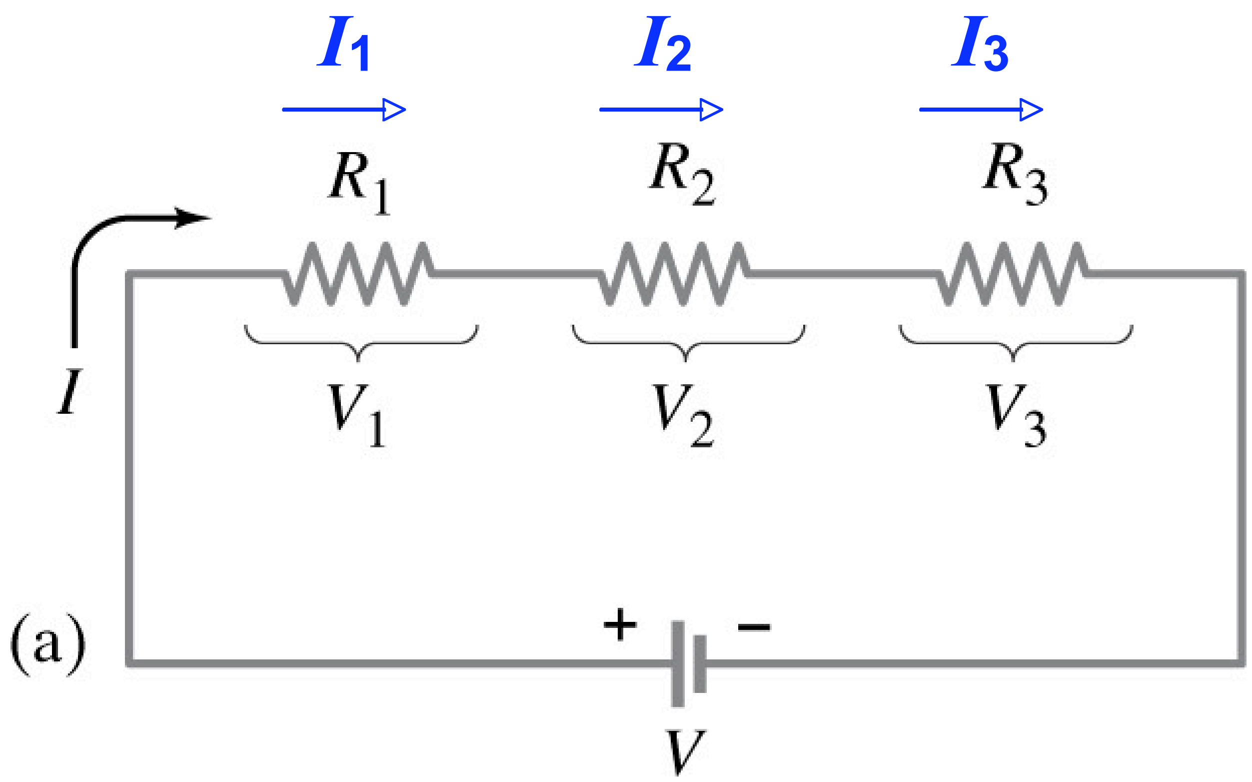
Physics 590B

Electrical signals generation and measurements

Torpedo nobiliana (Giant electric ray) Typical pulse: 50 A, 60 V

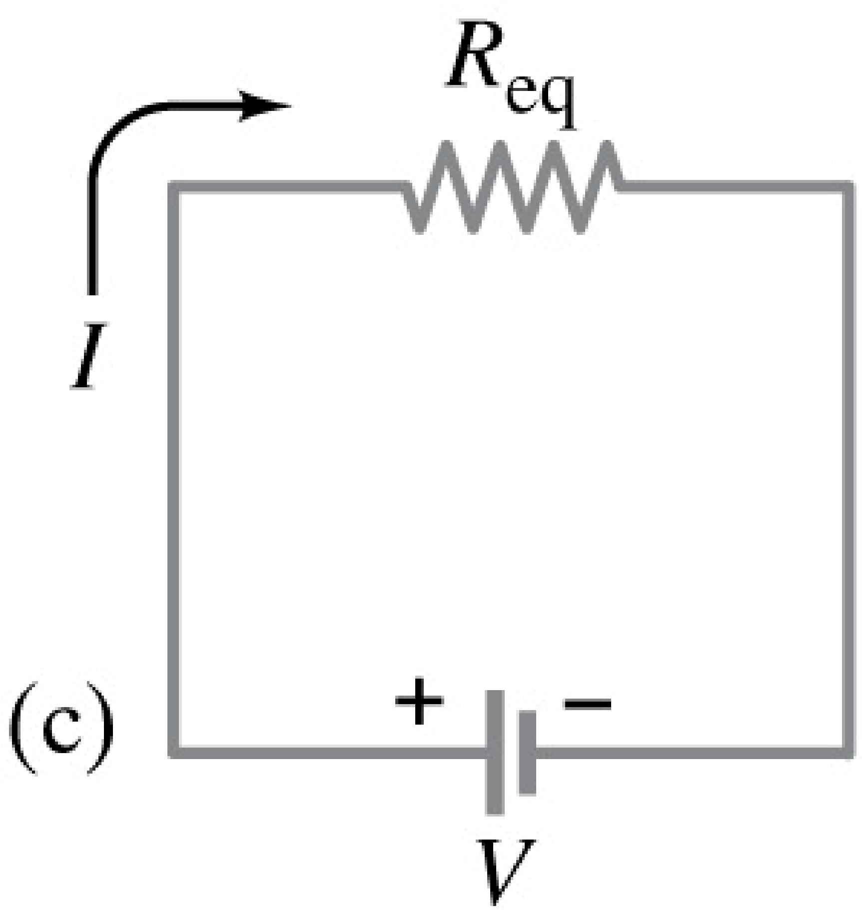
Connecting resistors in series



$$I_1 = I_2 = I_3 = I$$

$$V_1 = IR_1 \qquad V_2 = IR_2 \qquad V_3 = IR_3$$

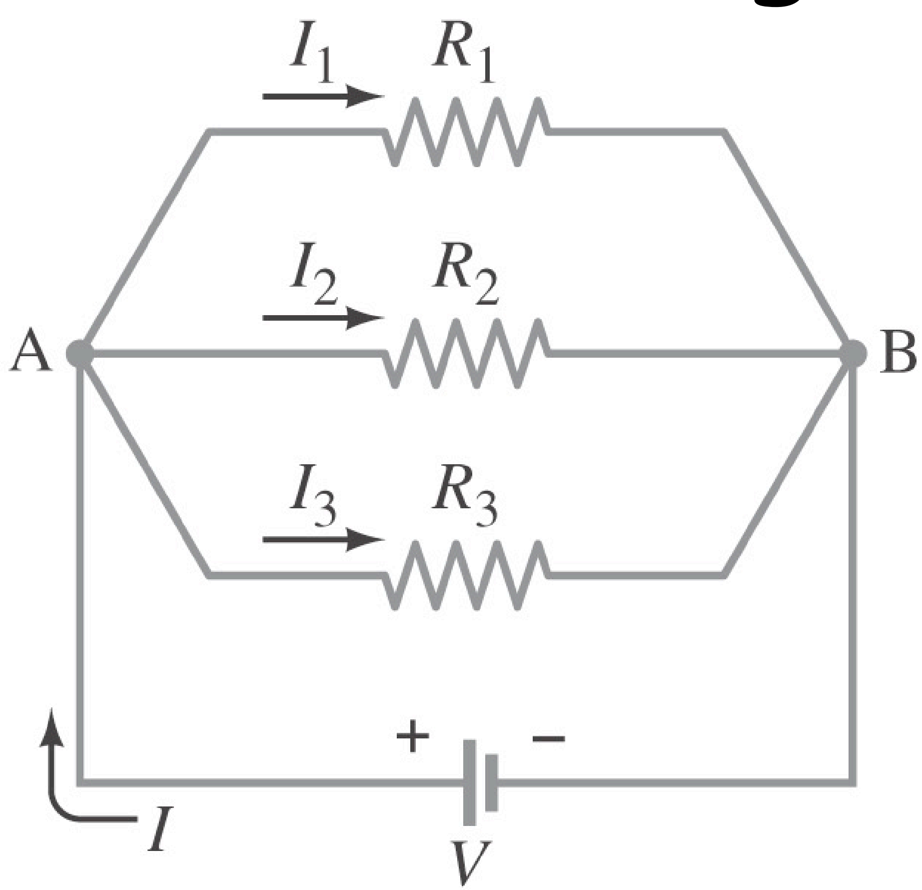
$$V = V_1 + V_2 + V_3$$



$V = IR_{eq}$ (same I and V as before)

$$\boxed{R_{eq} = R_1 + R_2 + R_3}$$

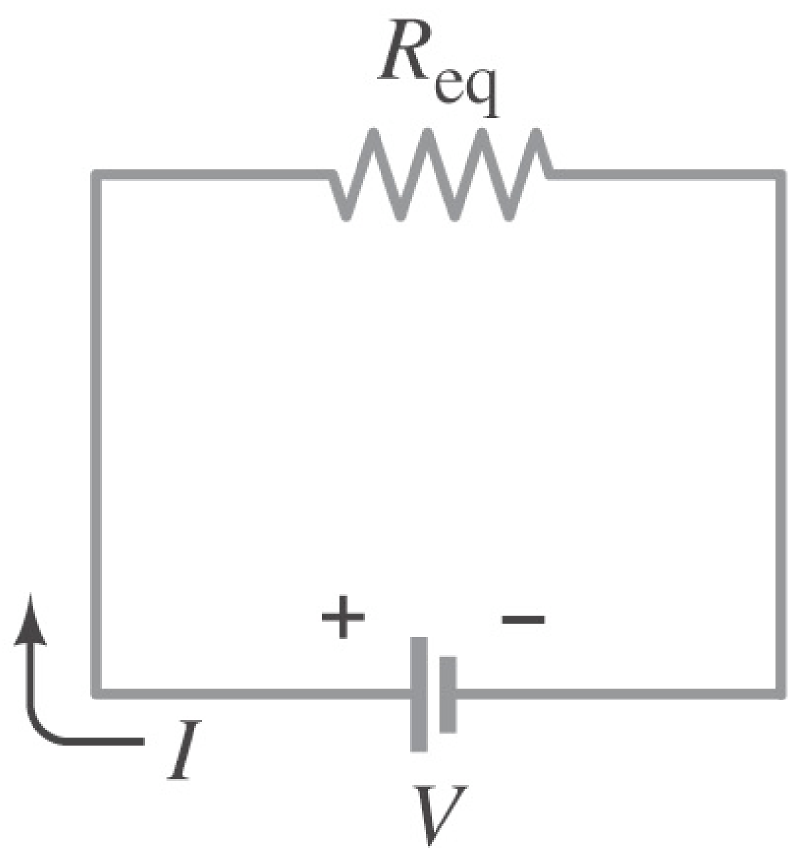
Connecting resistors in parallel



$$I = I_1 + I_2 + I_3$$

$$V = V_1 = V_2 = V_3$$

$$V = I_1R_1 \quad V = I_2R_2 \quad V = I_3R_3$$

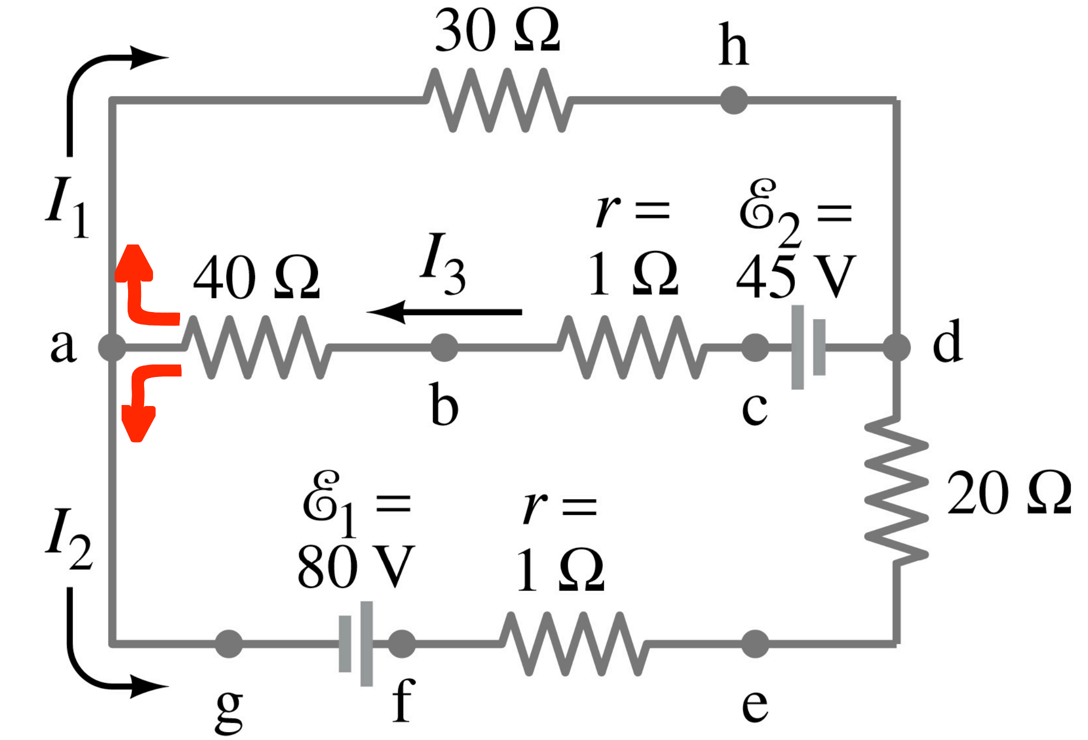


$V = IR_{eq}$ **(same I and V as before)**

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

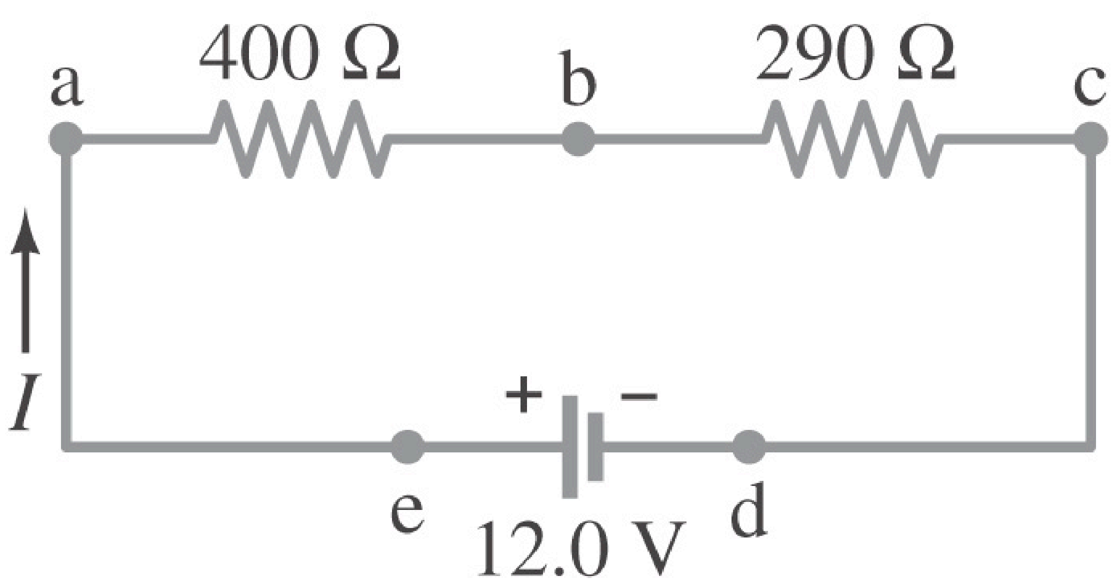
Kirchhoff's rules

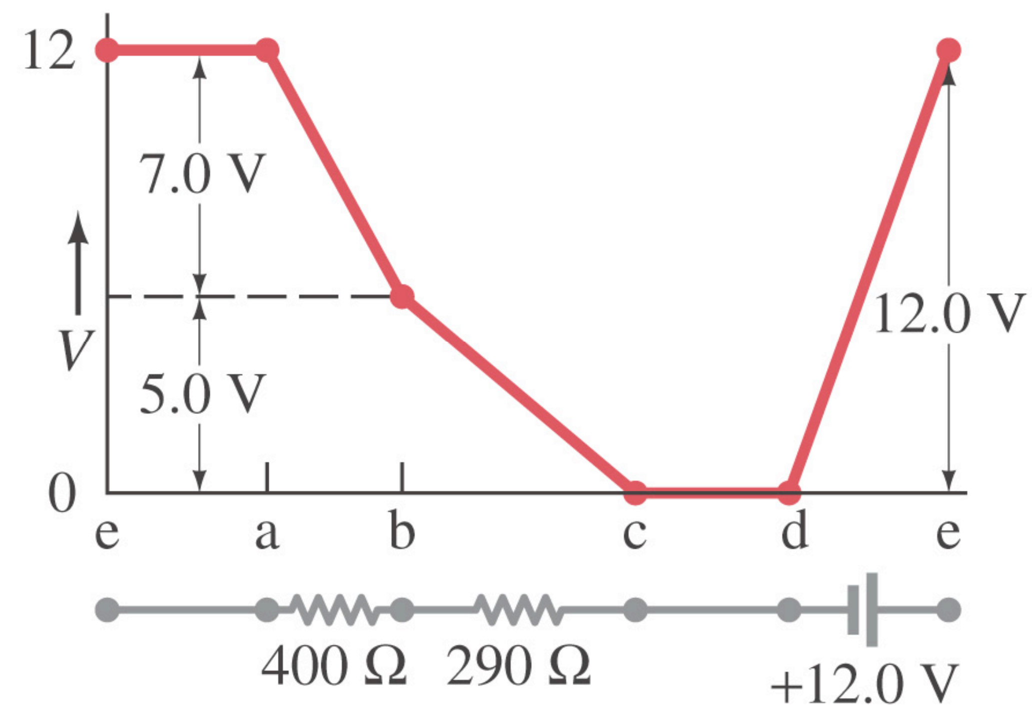
Junction rule: Sum of currents entering a junction equals the sum of the currents leaving it.



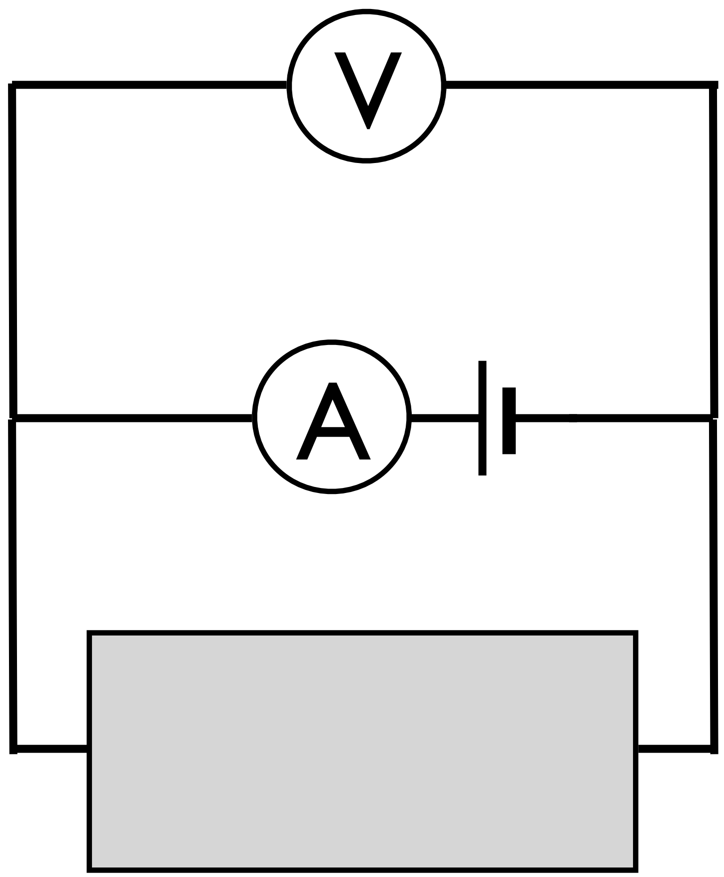
e.g. at a,
$I_3 = I_1 + I_2$

Loop rule: The sum of the changes in potential around a closed loop is zero.

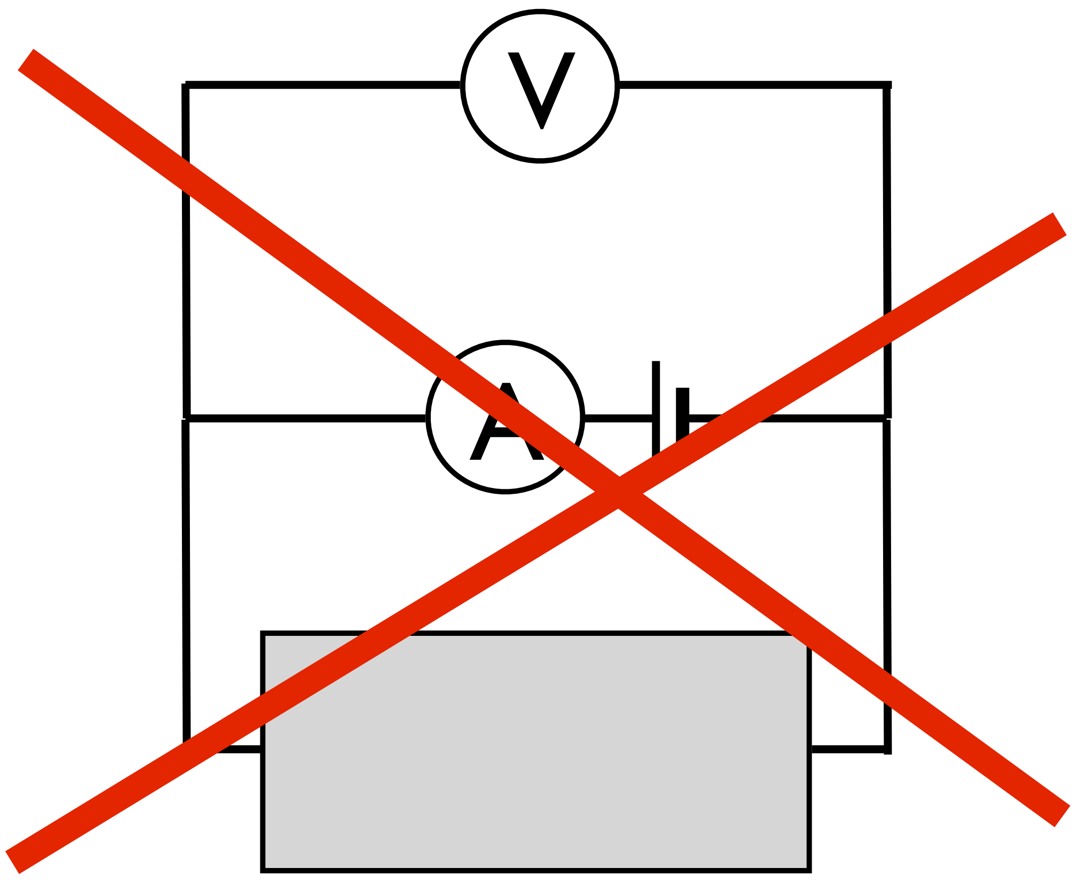




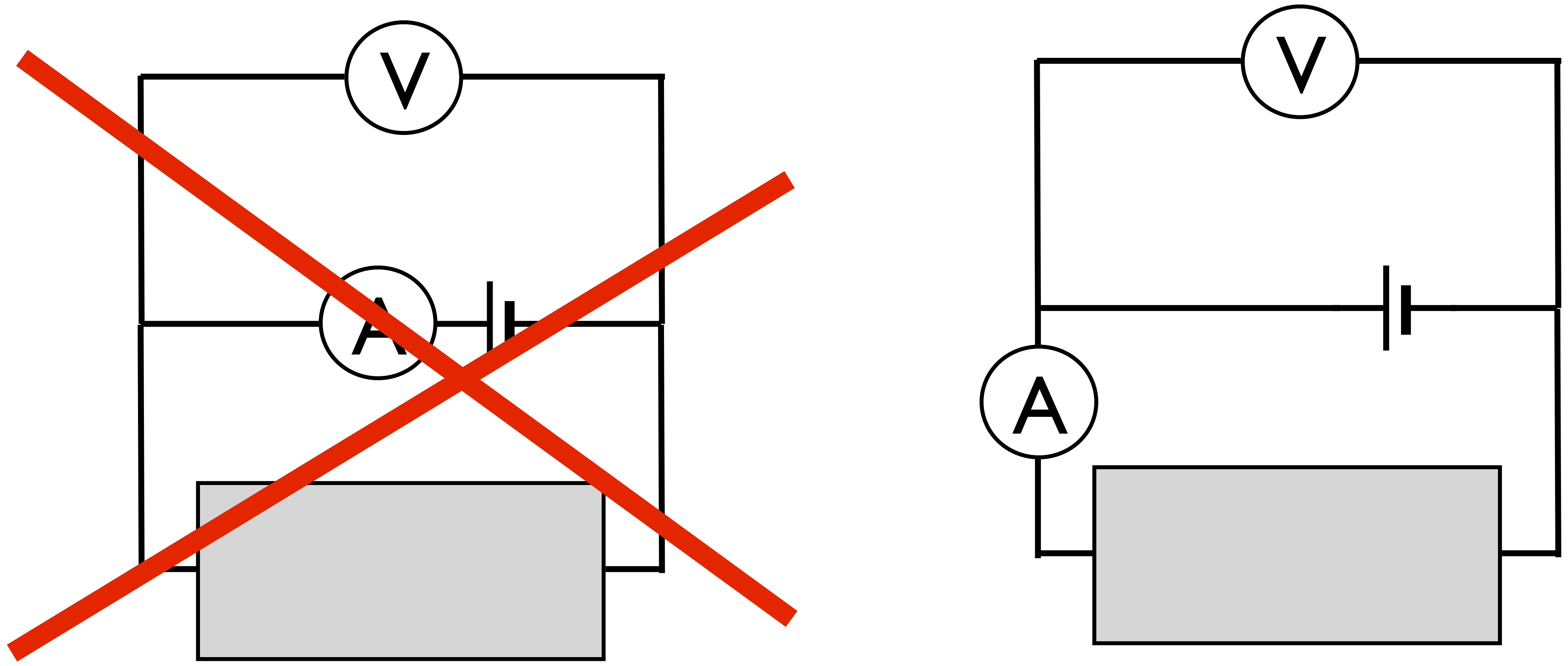
Resistivity measurements



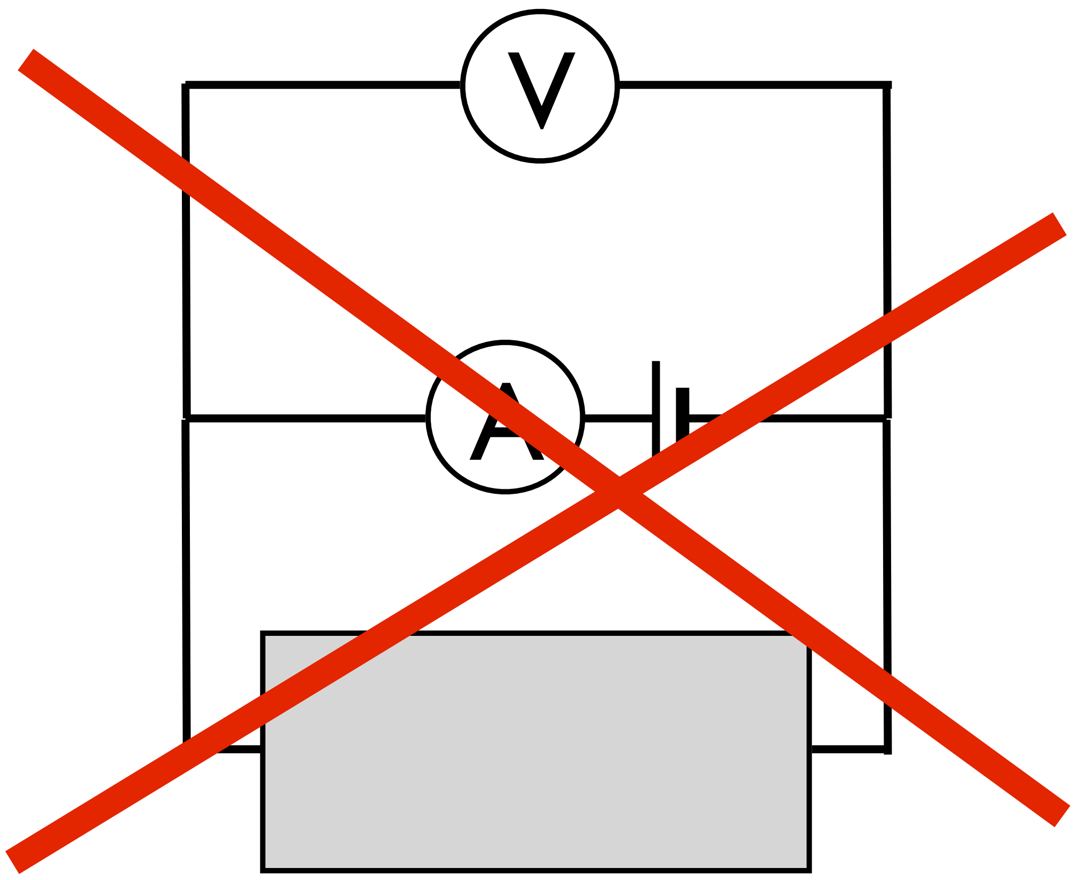
Resistivity measurements

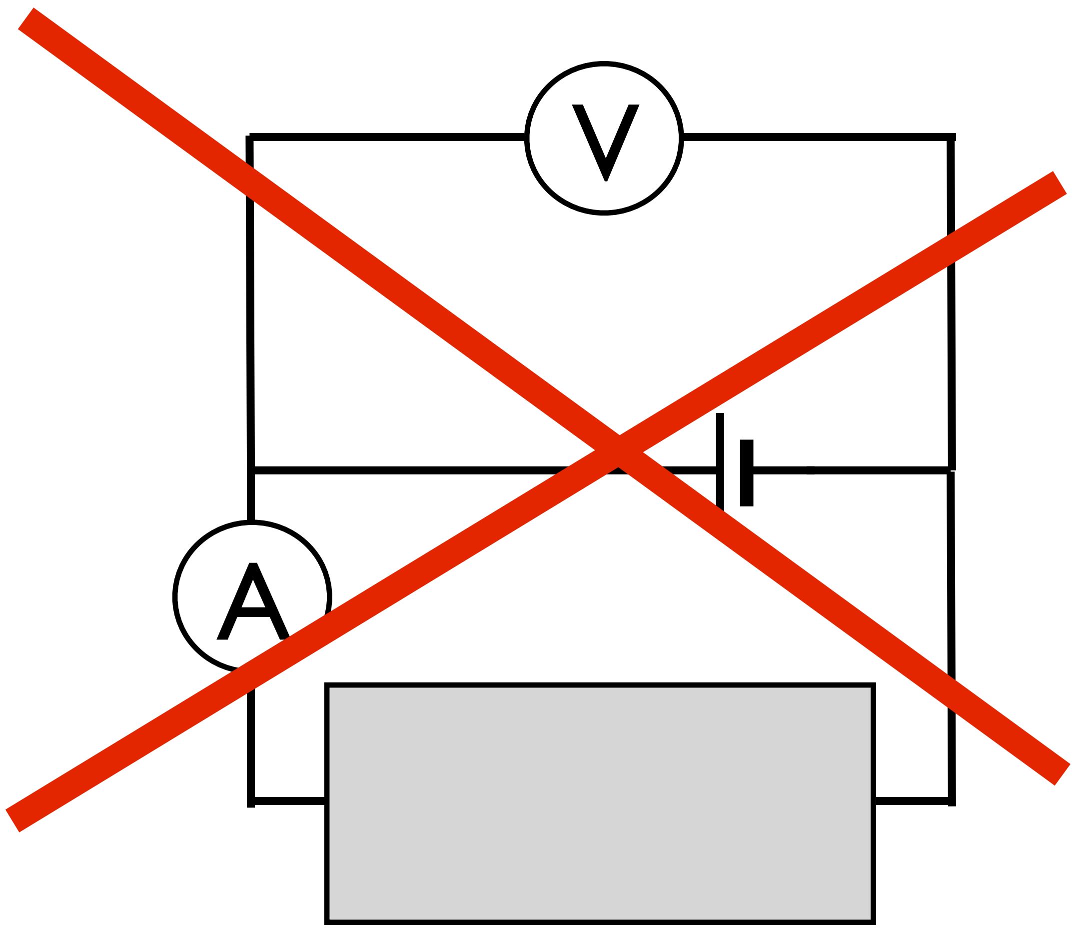


Resistivity measurements

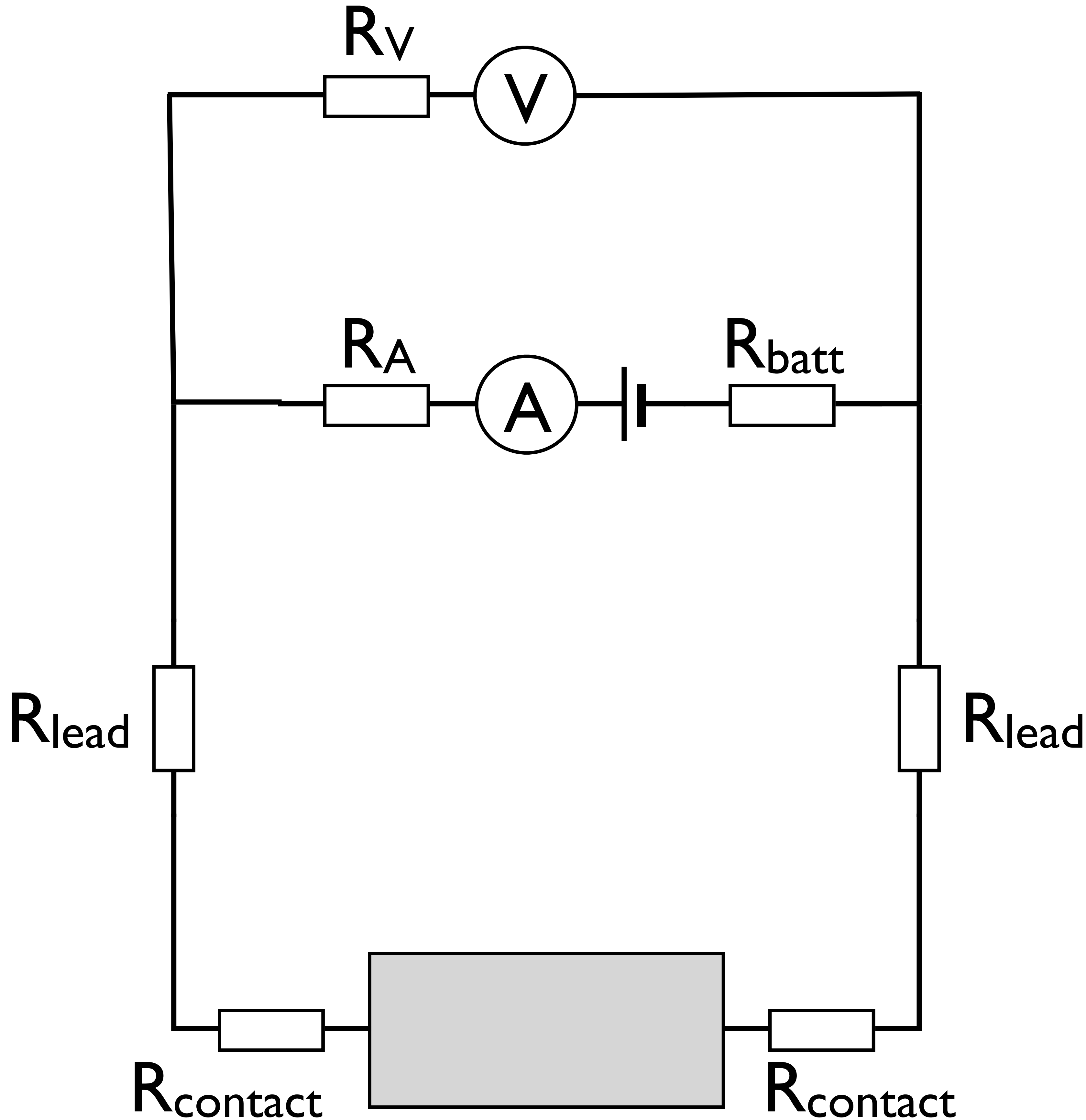


Resistivity measurements

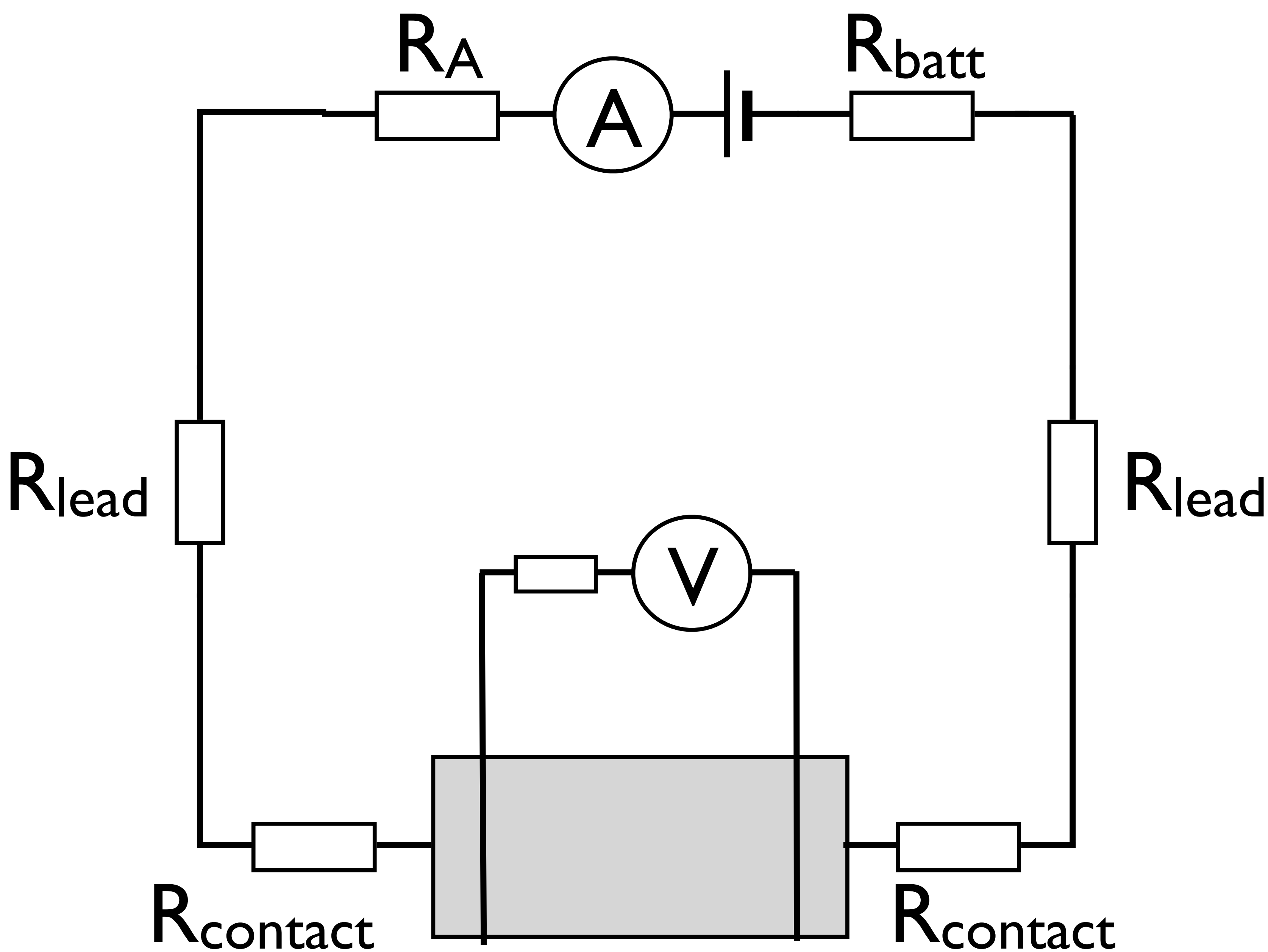


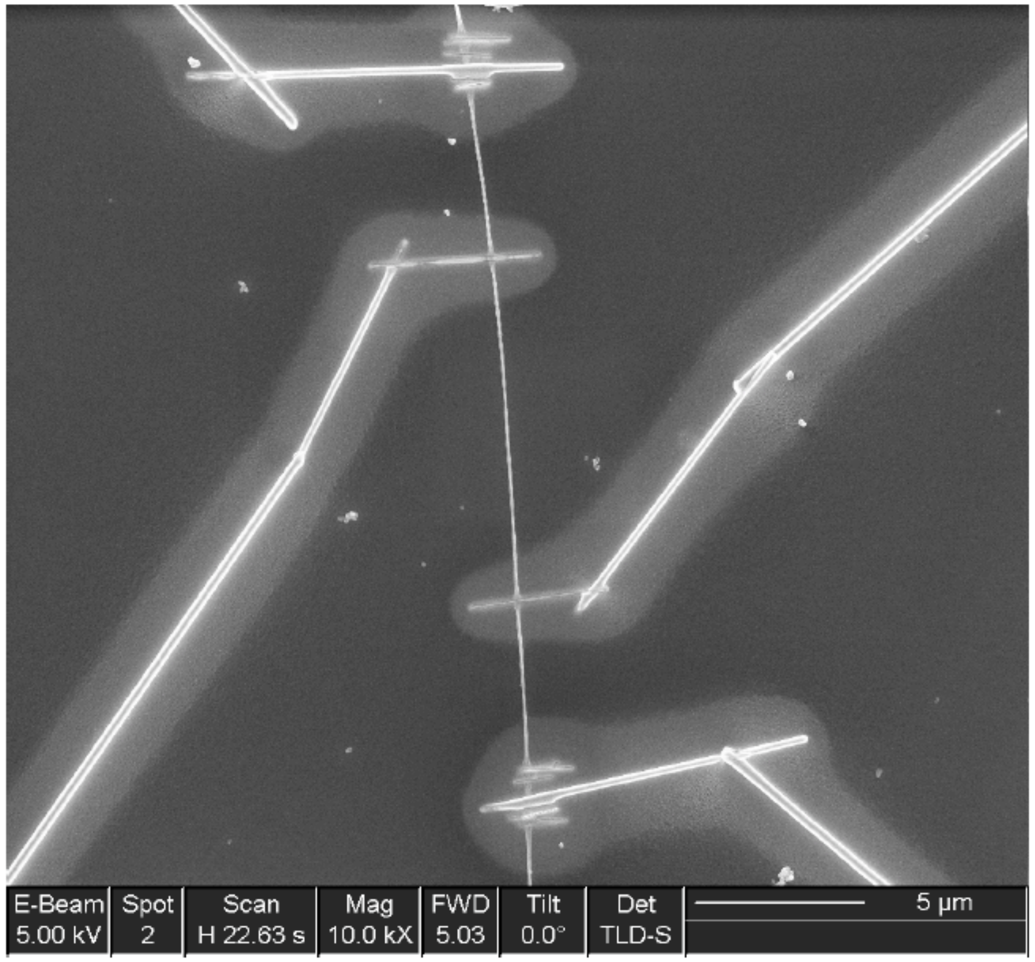


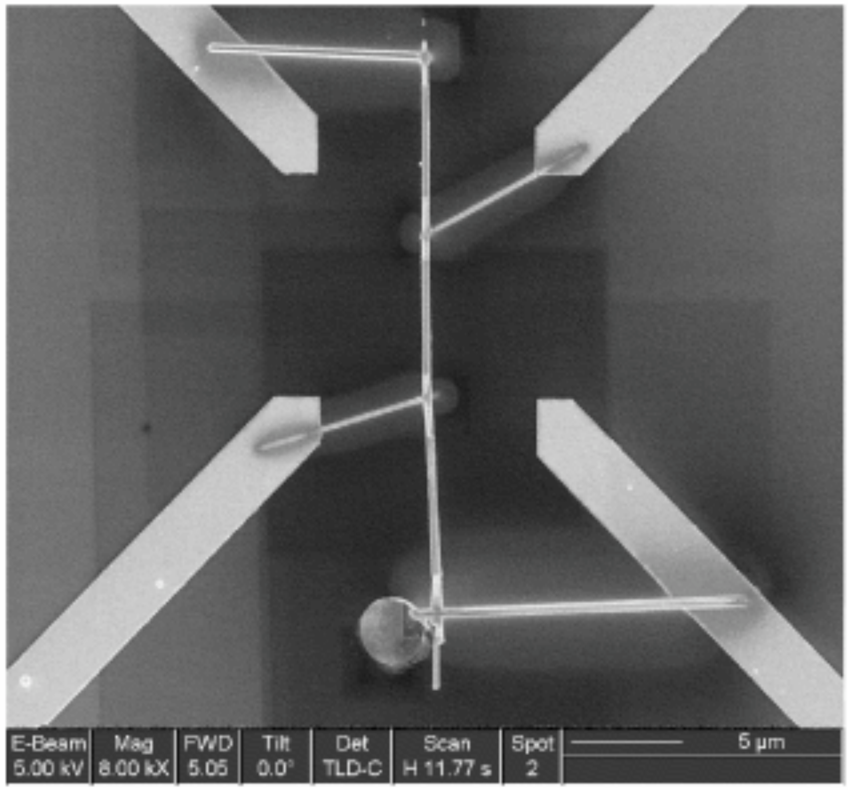
Real circuit



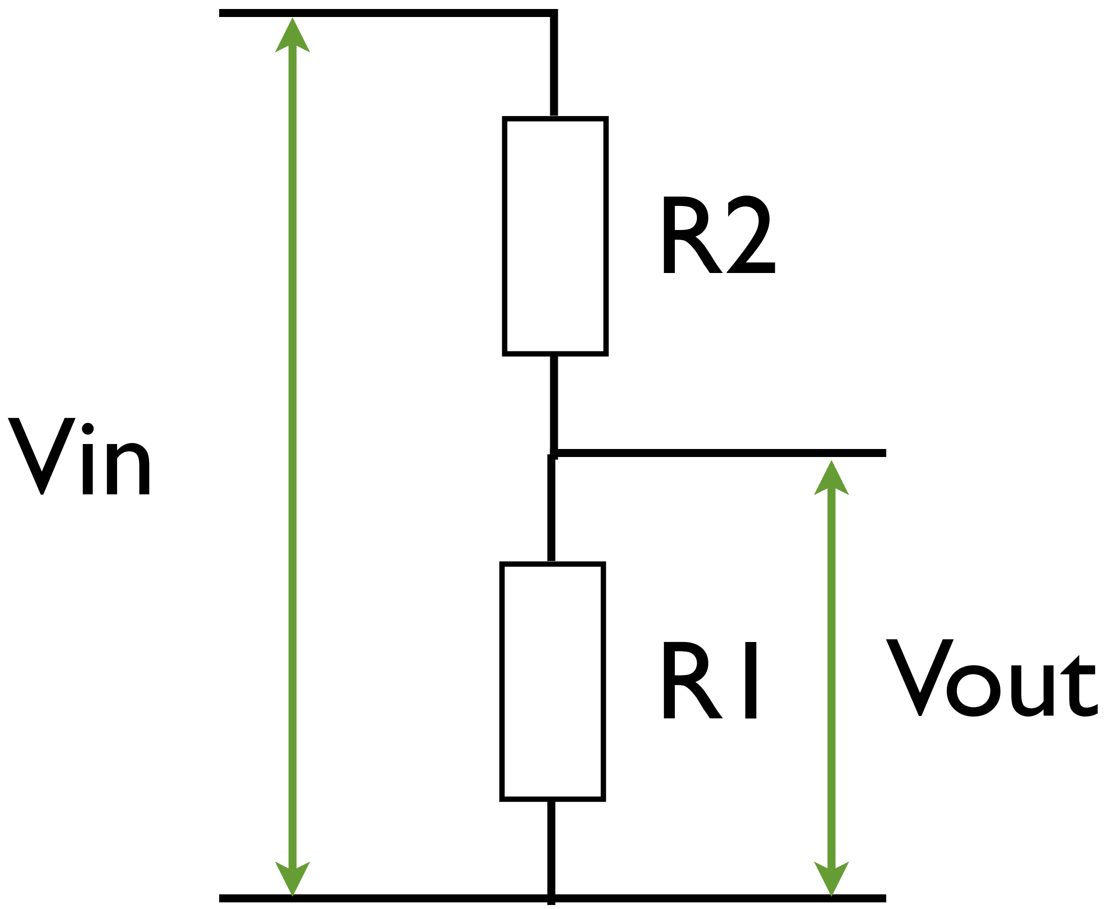
Solution: four point contact measurement




E-Beam
5.00 kV
Spot
2
Scan
H 22.63 s
Mag
10.0 kX
FWD
5.03
Tilt
0.0°
Det
TLD-S
5 µm

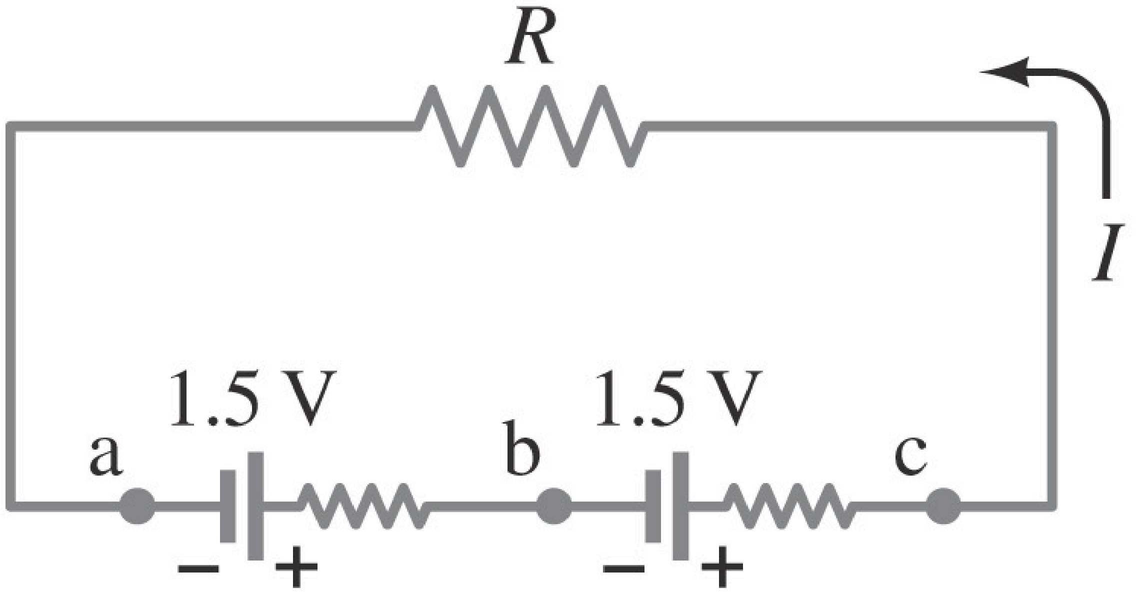

E-Beam
5.00 kV
Mag
8.00 kX
FWD
5.05
Tilt
0.0°
Det
TLD-C
Scan
H 11.77 s
Spot
2
5 µm

Simplest circuit: voltage divider

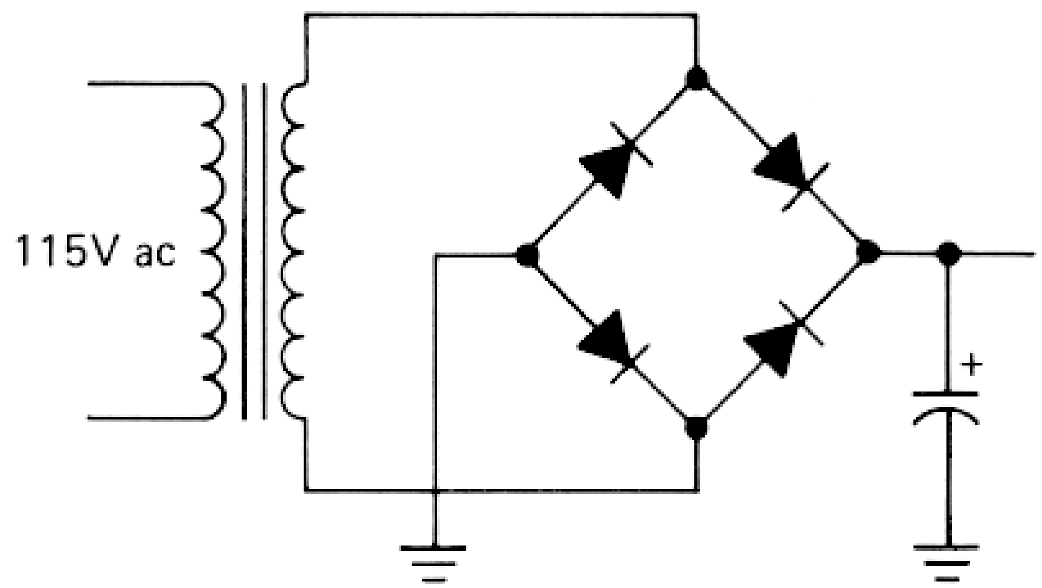


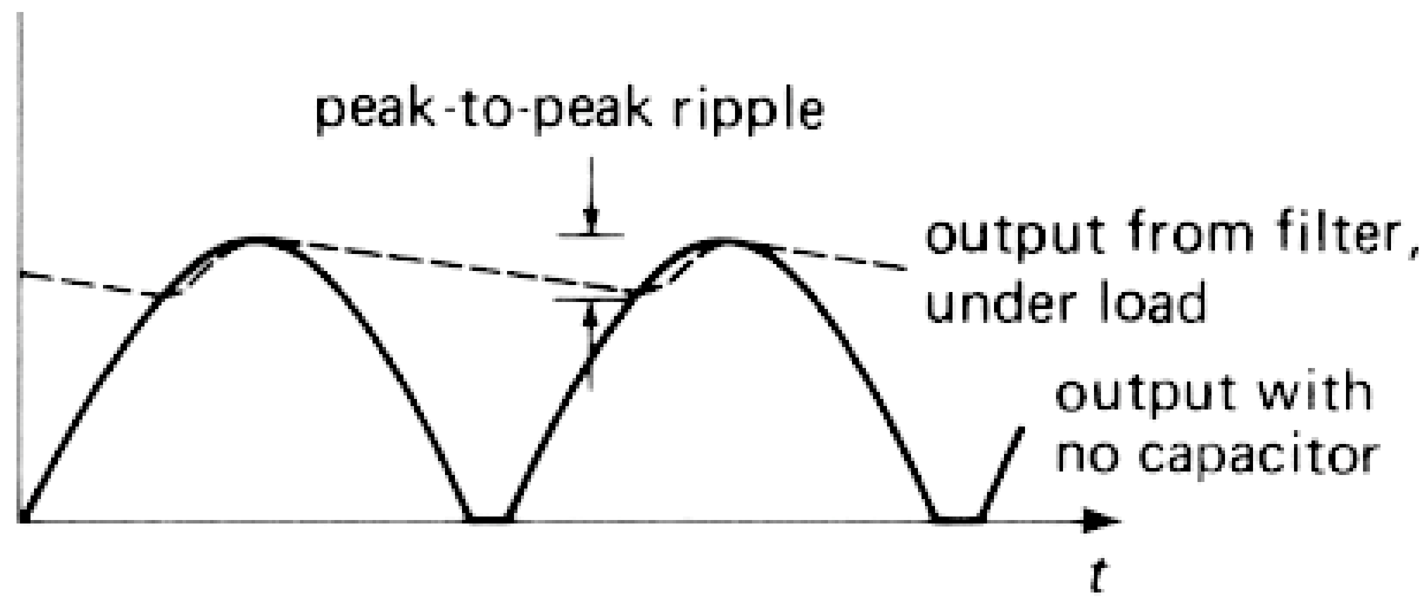
$$\text{Vout} = \text{Vin}\,\frac{\text{R1}}{\text{R1}+\text{R2}}$$

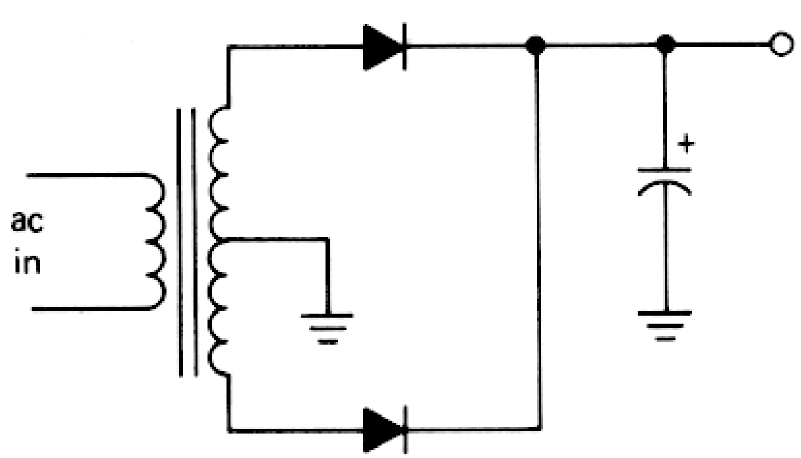
Batteries

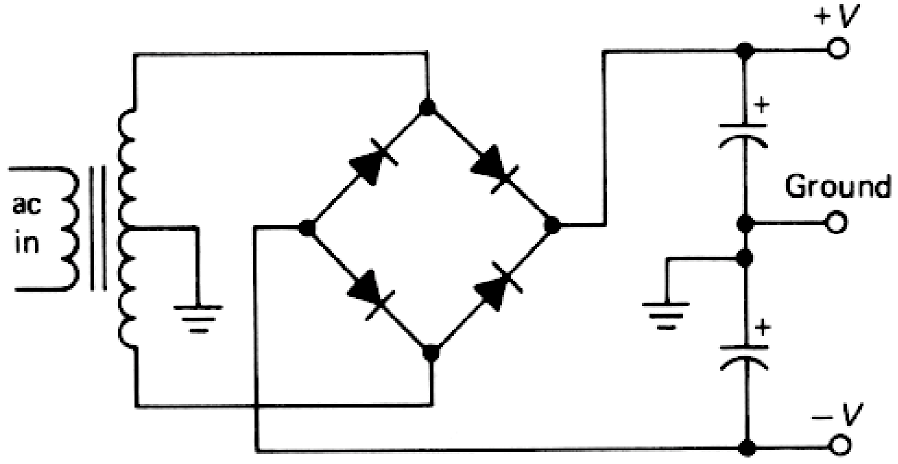


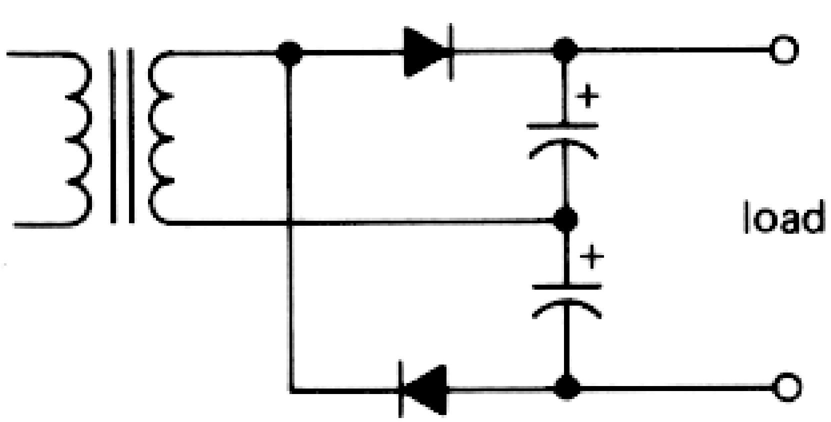
Analog power supplies





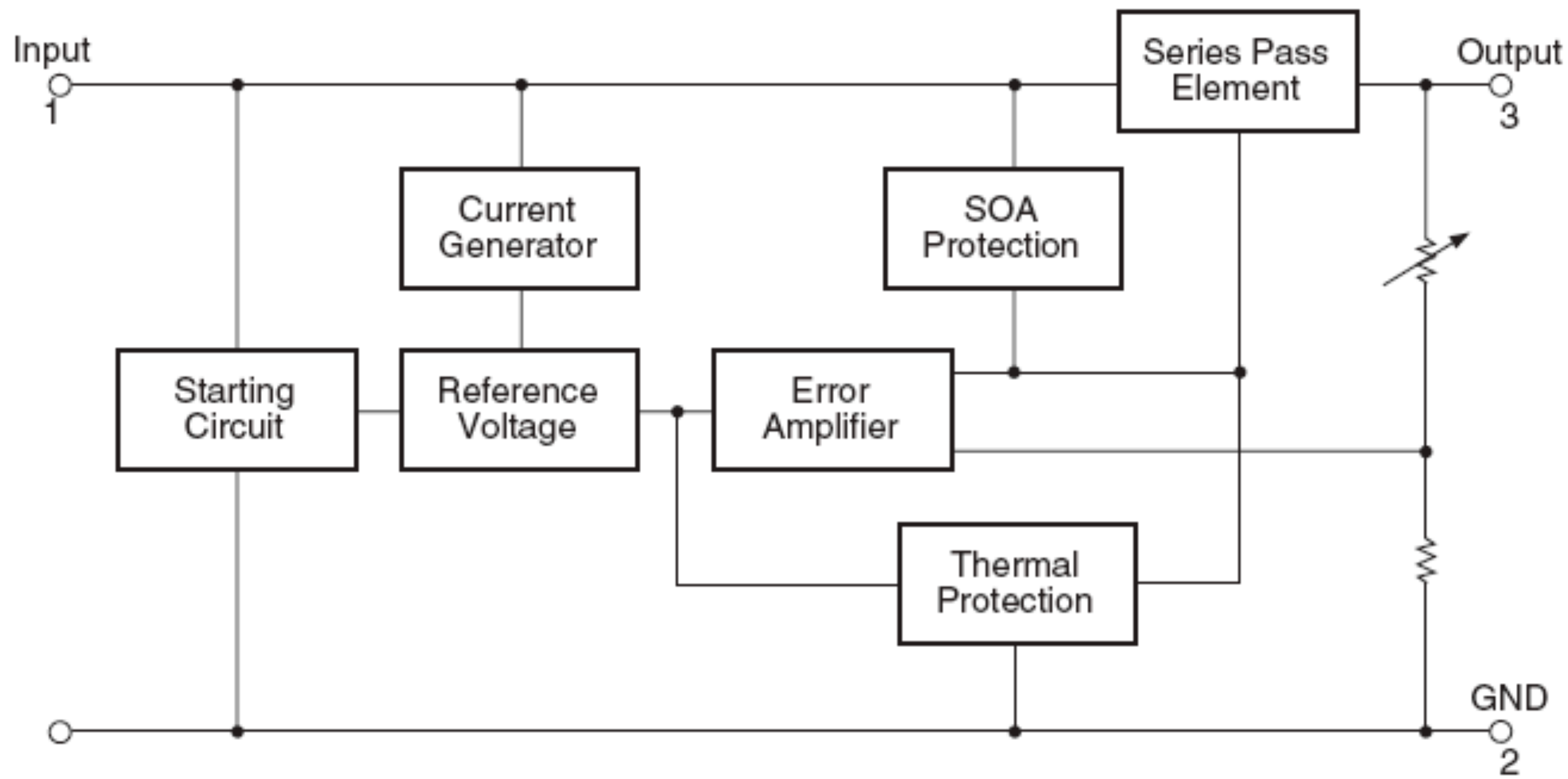


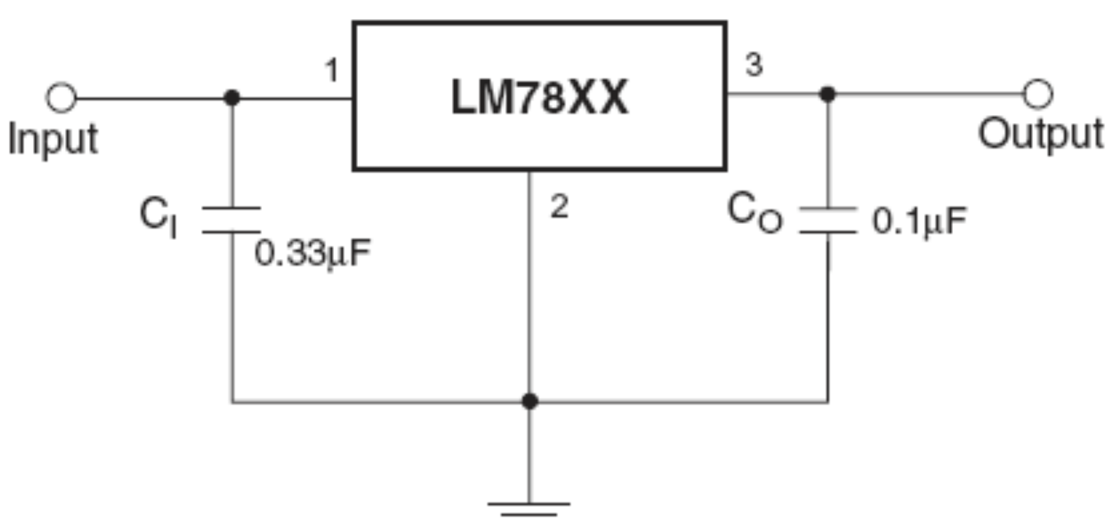




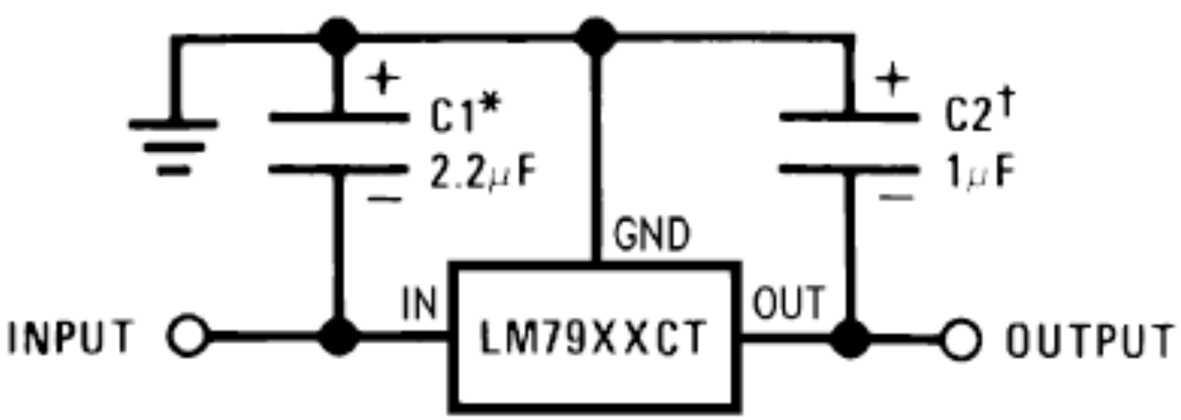
Voltage regulators

Block Diagram



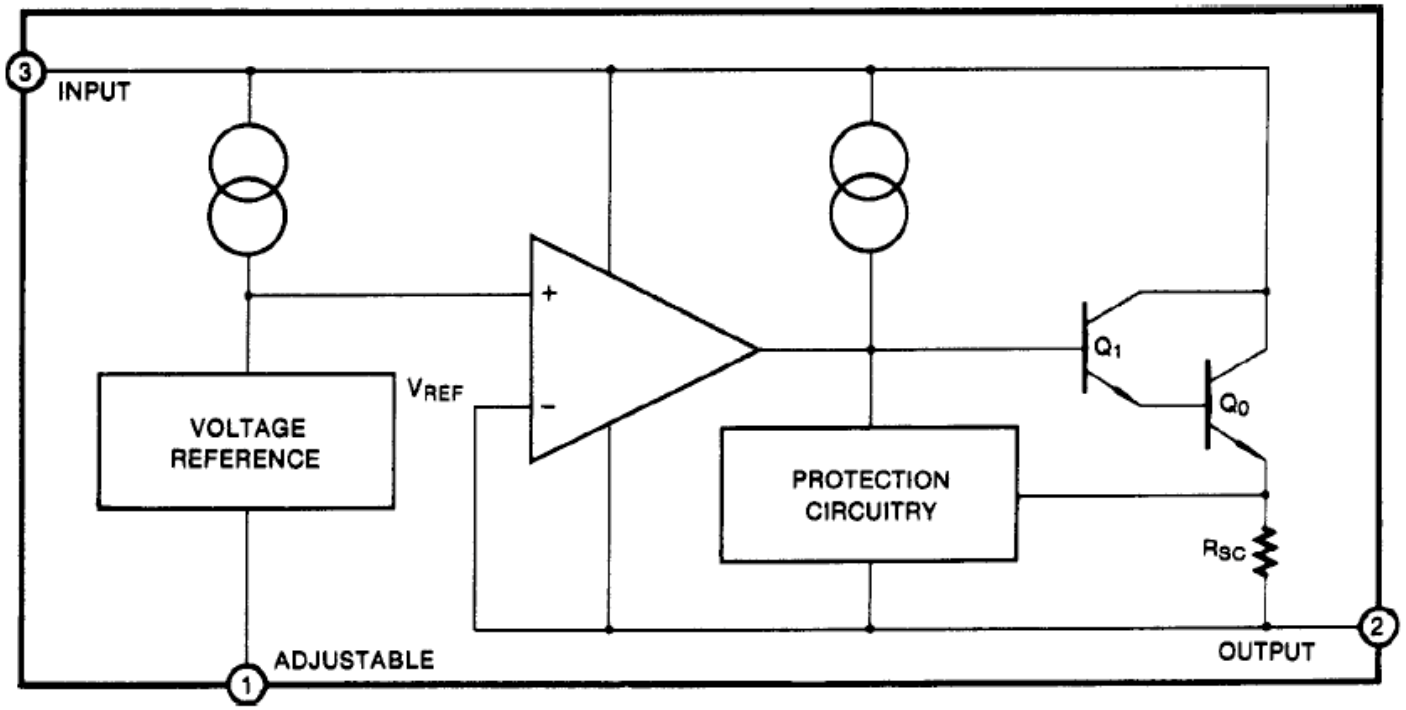


Fixed Regulator

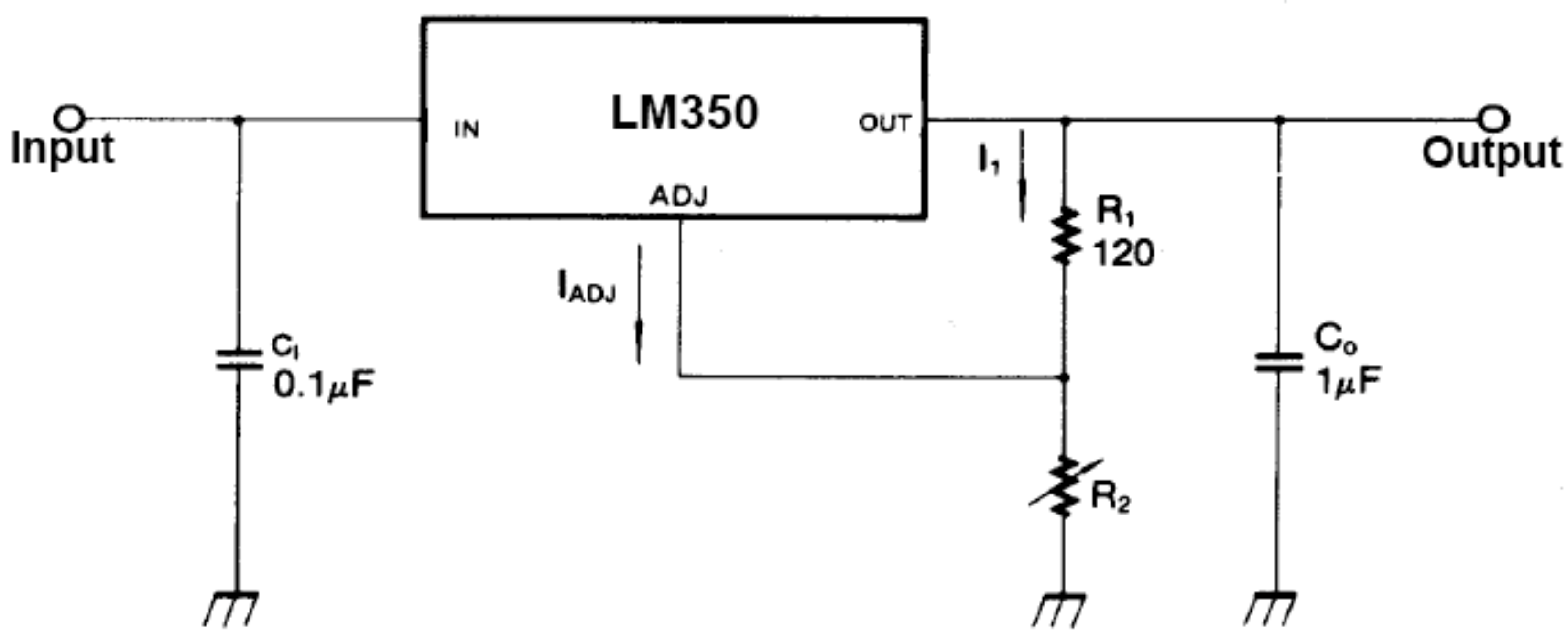


XX=05, 06, 08, 09, 10, 12, 15, 18, 24V

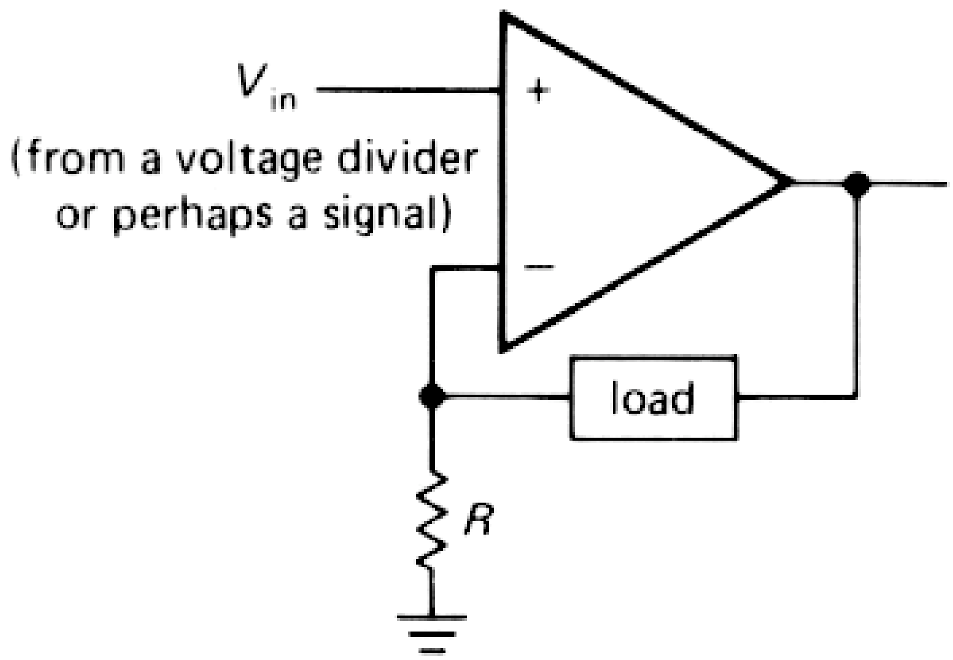
Adjustable voltage regulators

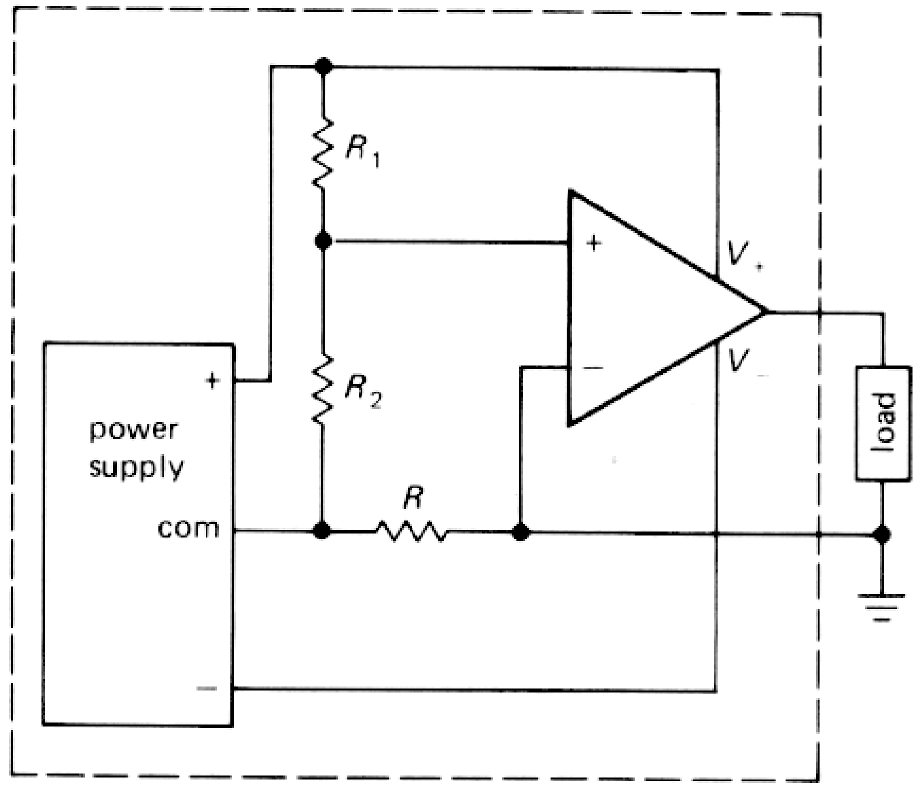


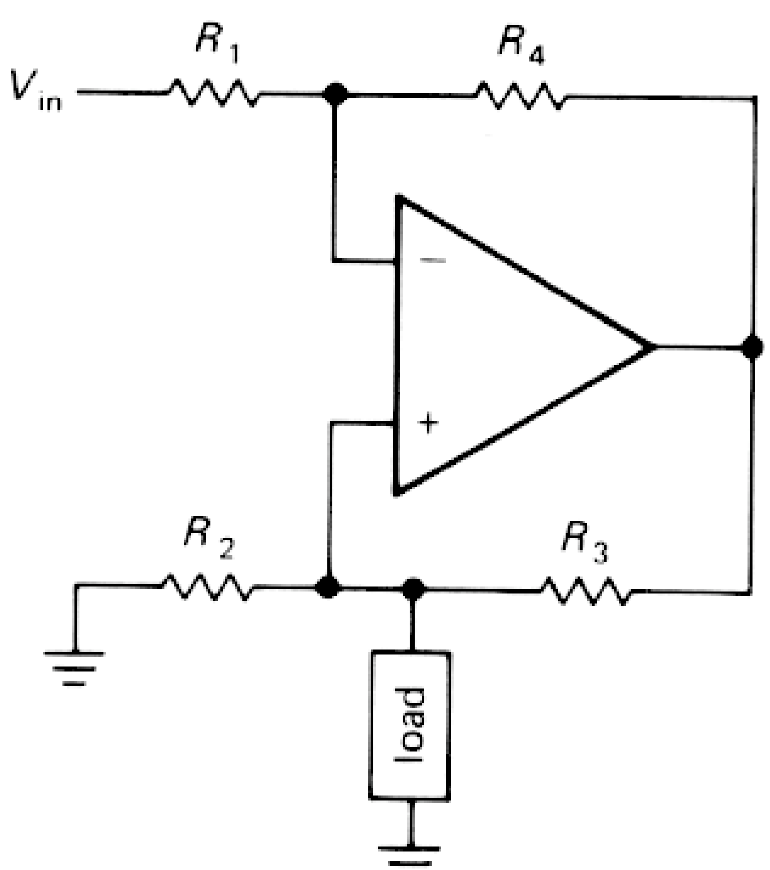
LM350: 3V-35V



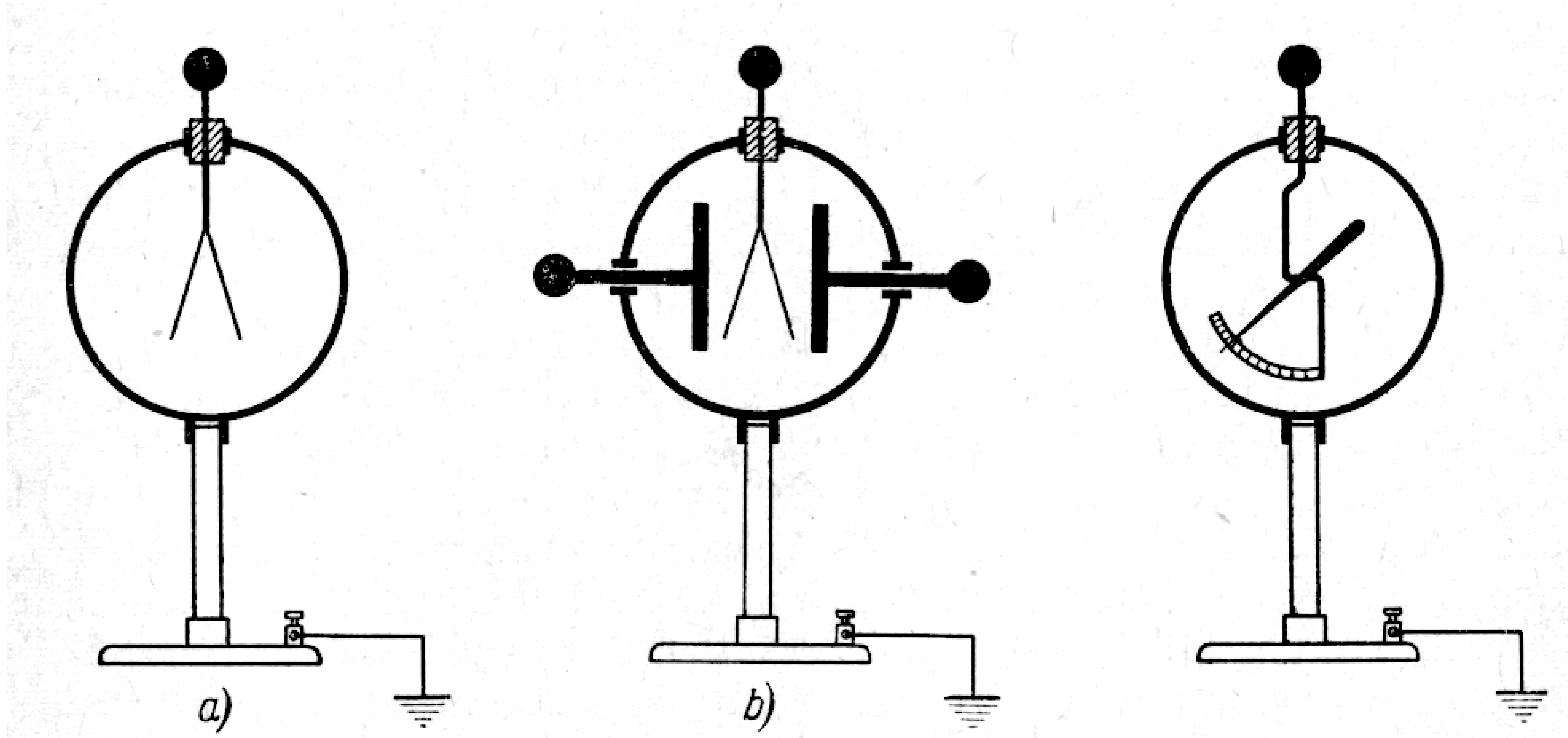
Current sources

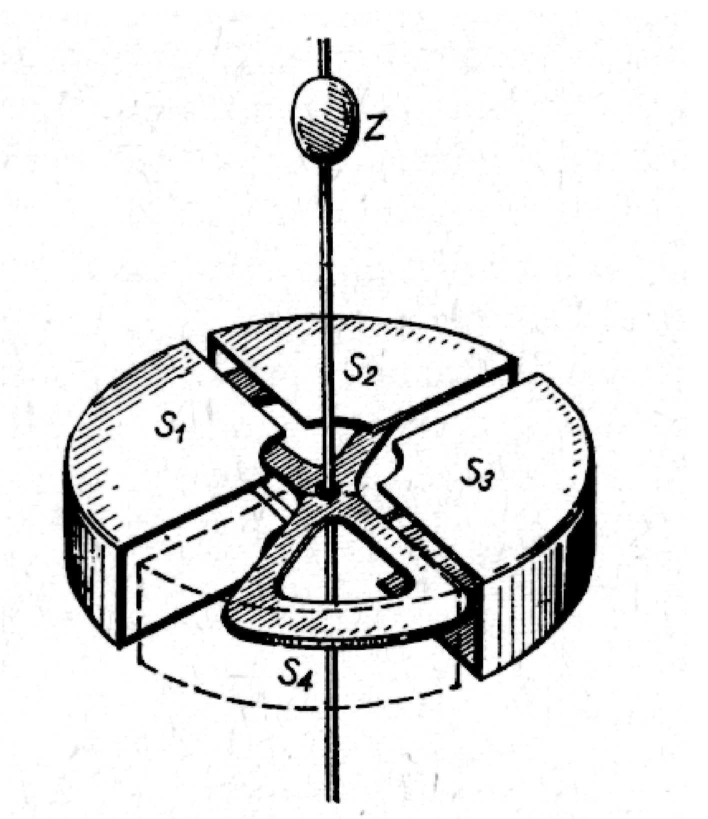


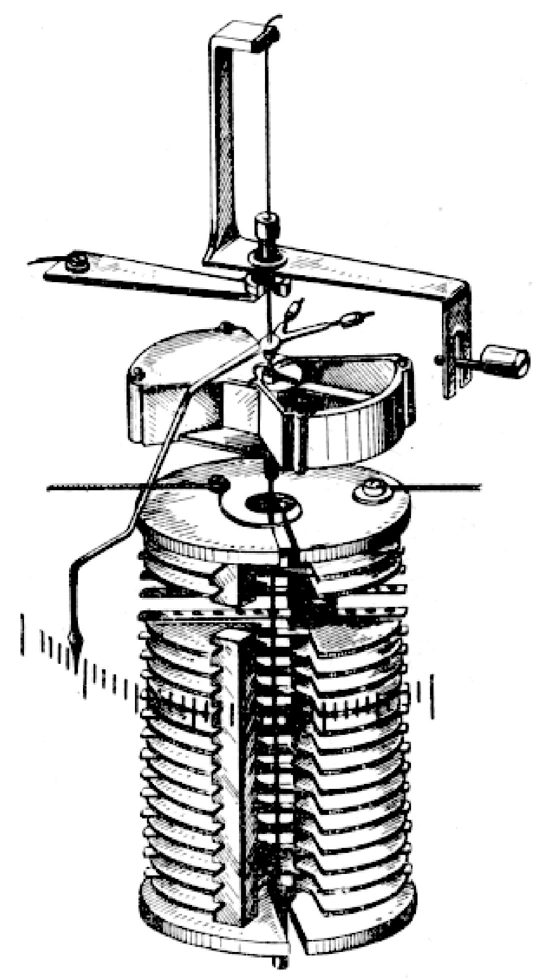


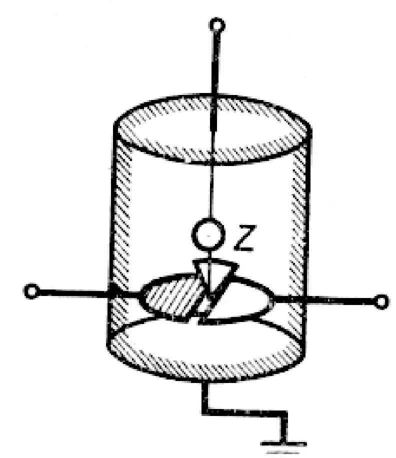


Electrometers

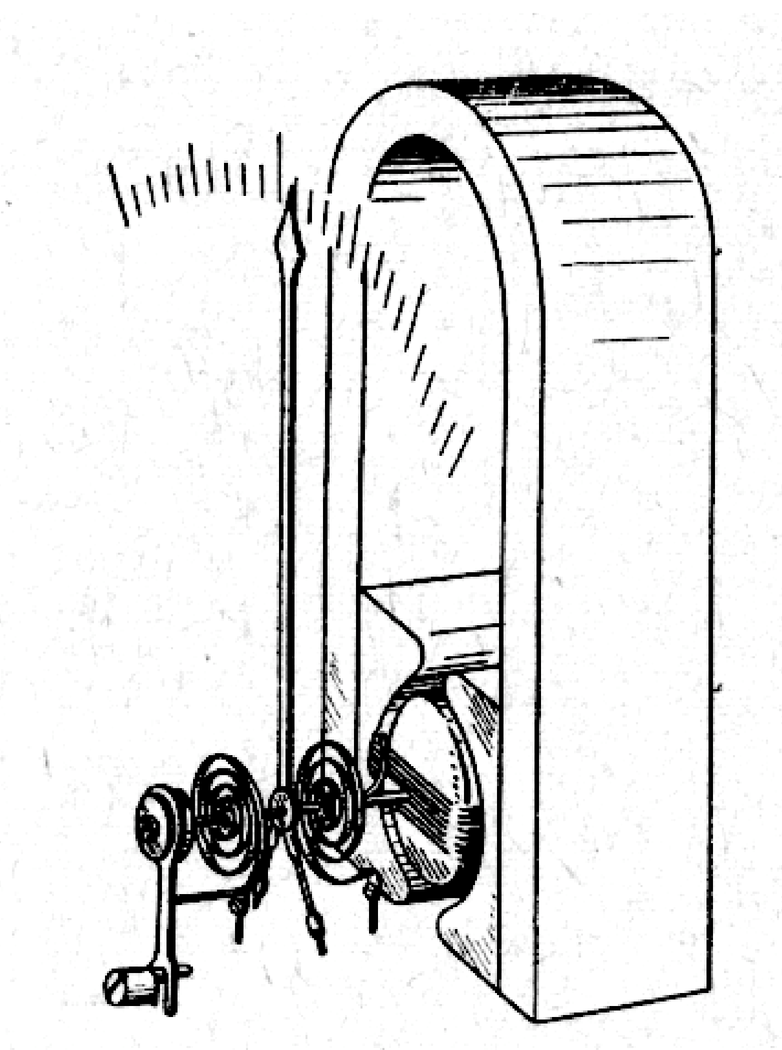
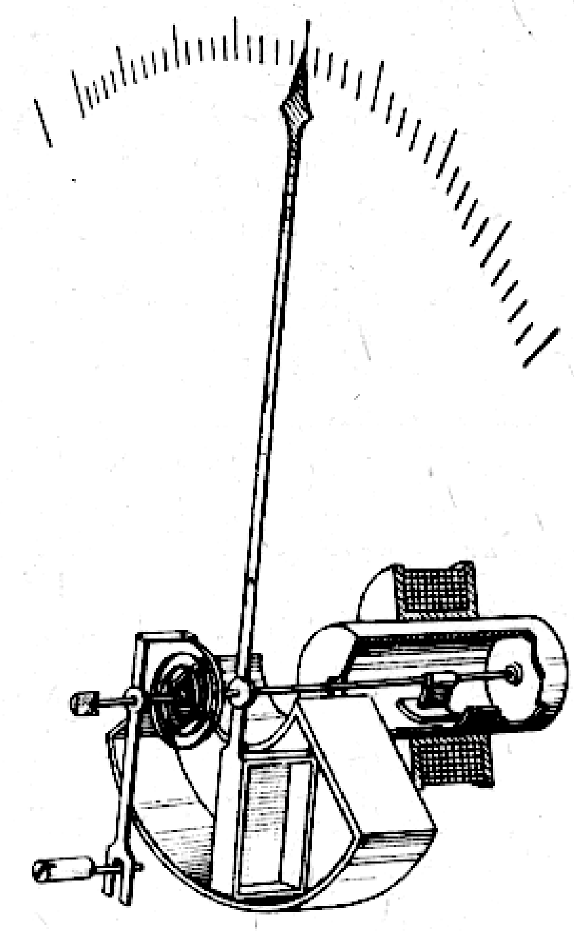
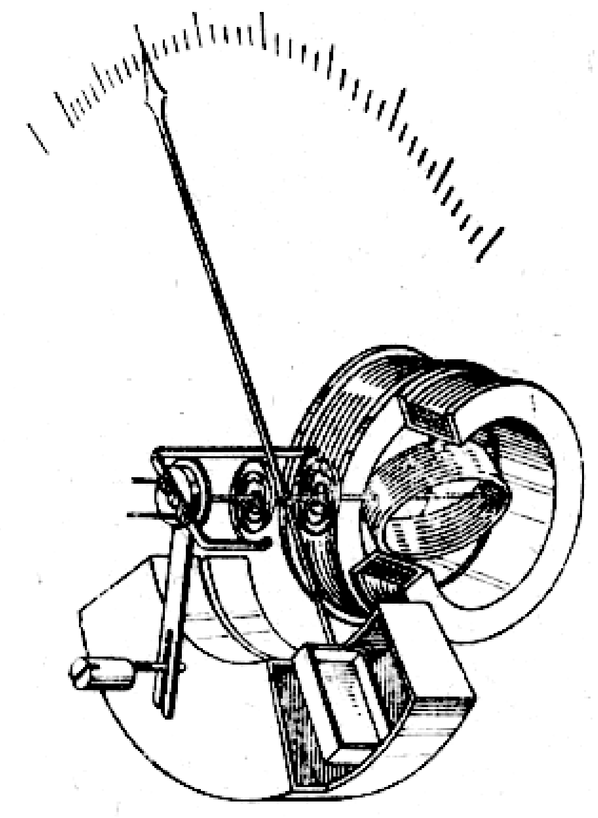




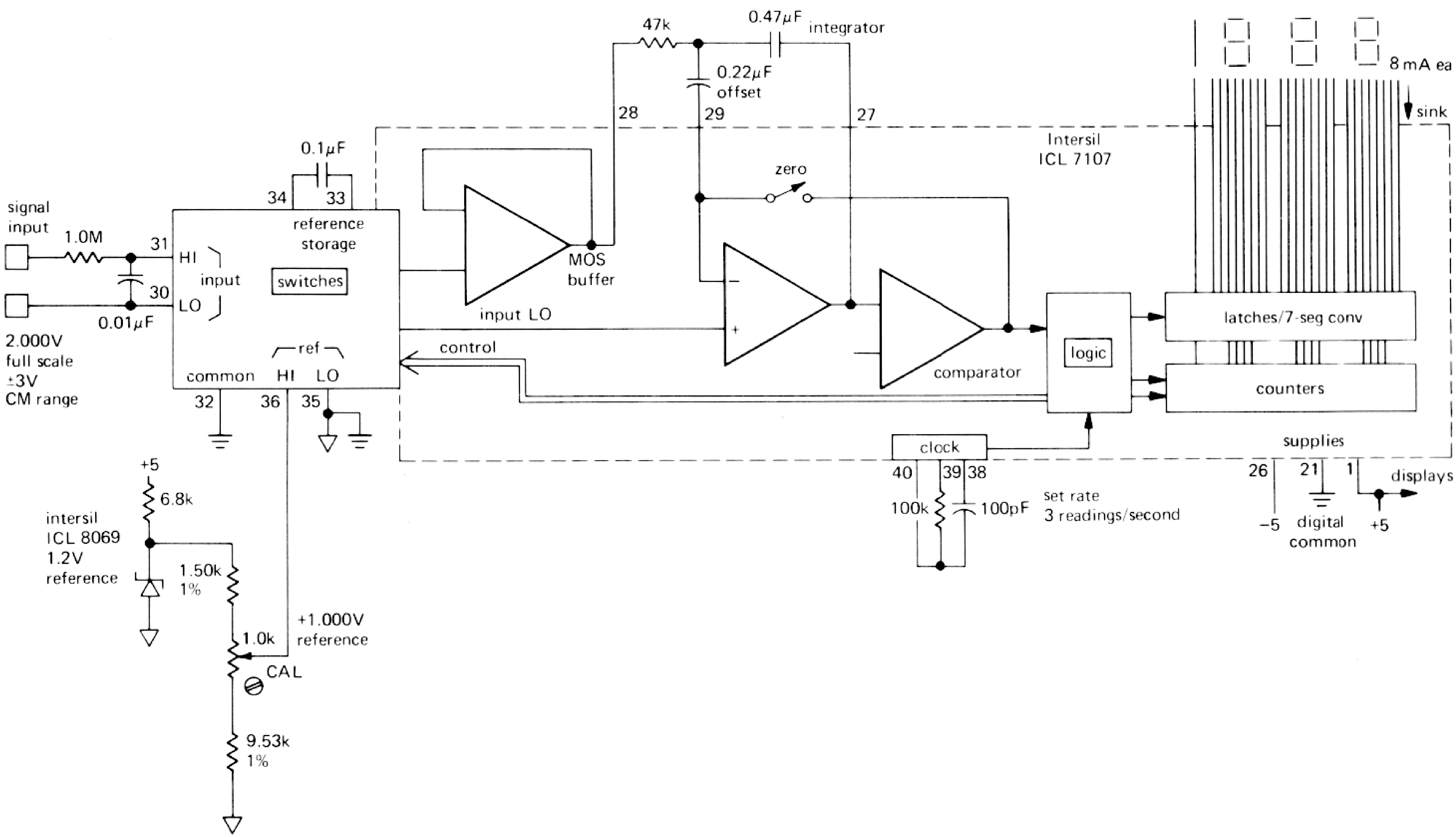




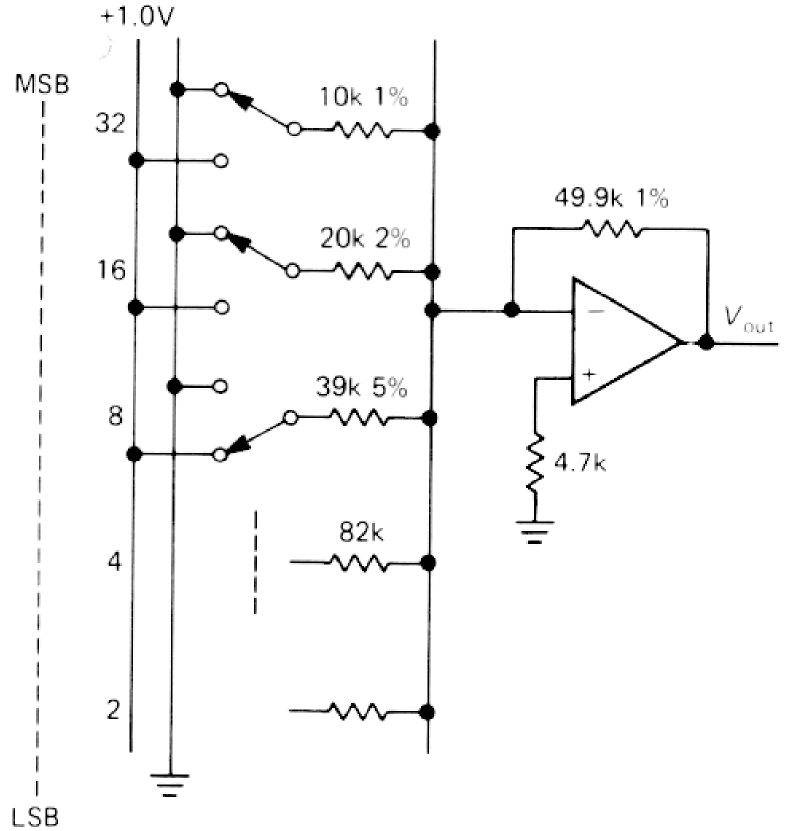
Current meters

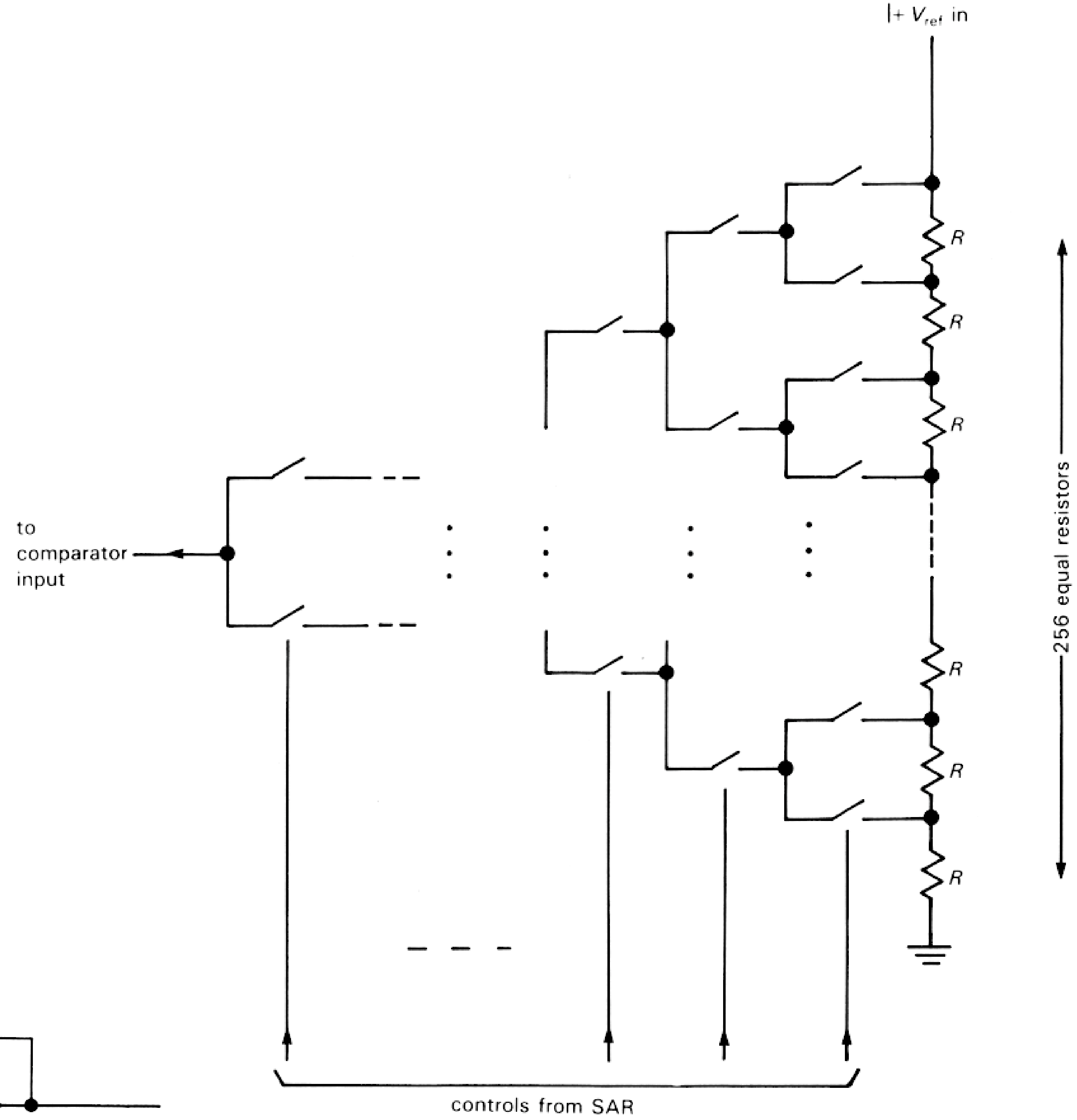




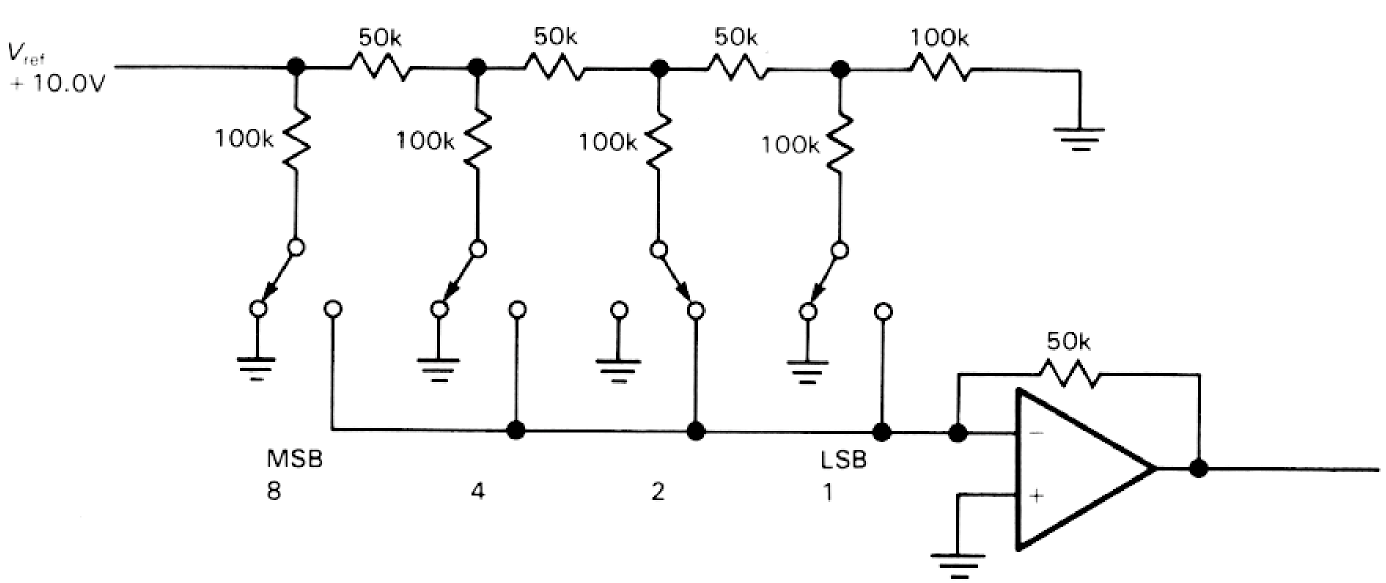
Digital volt meter (DVM)



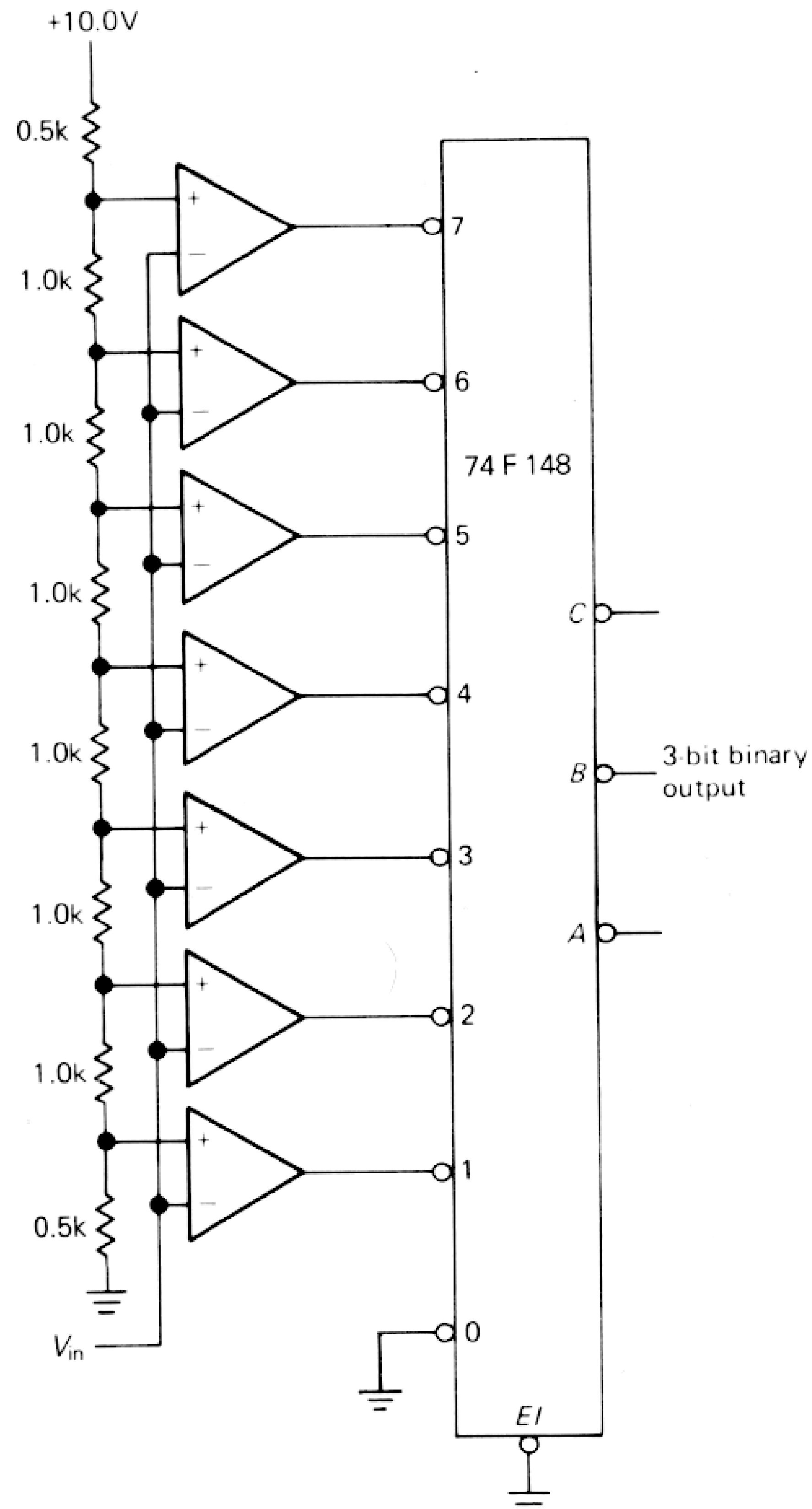
Digital to analog converters (DAC)



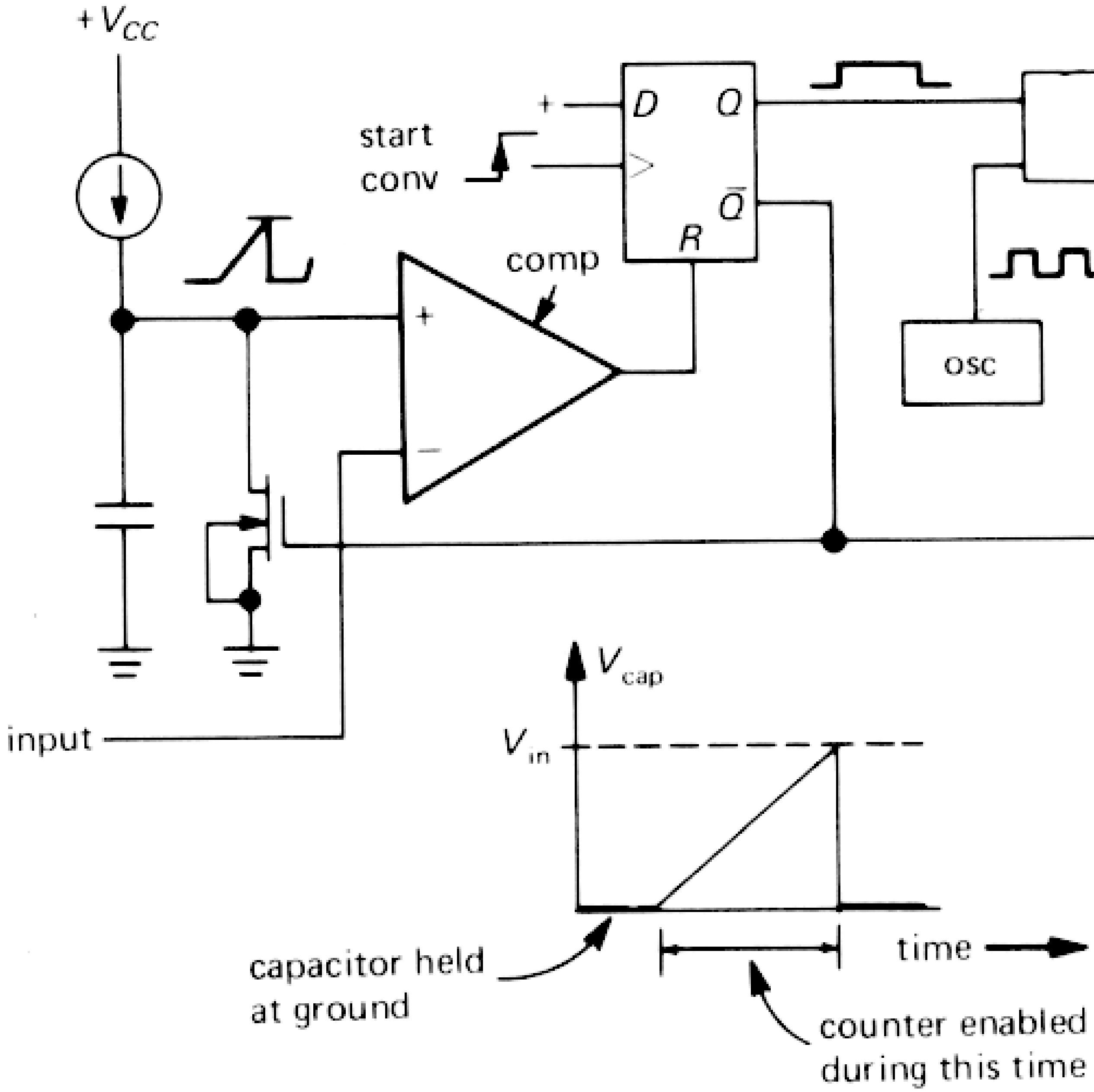




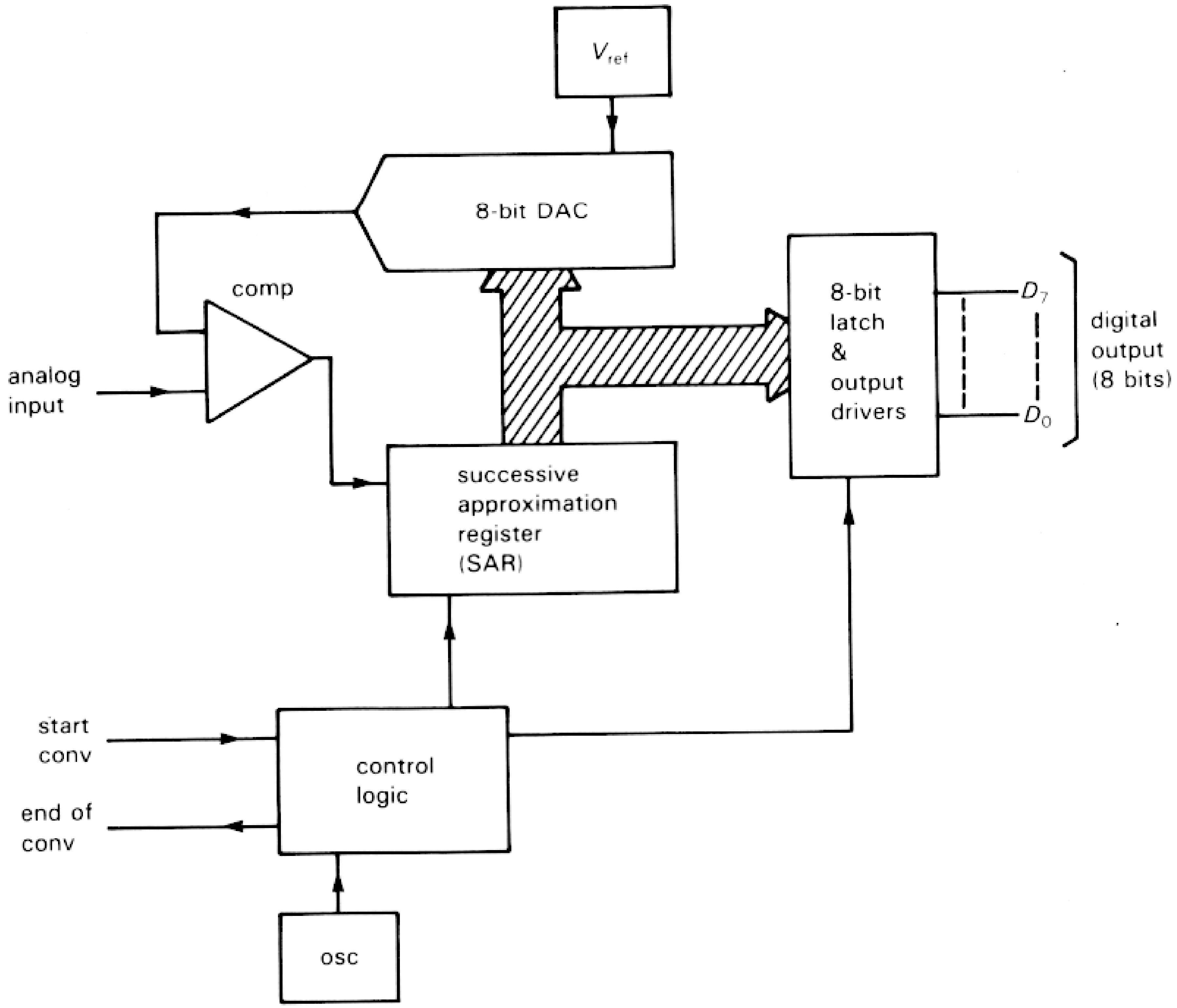
Analog to digital converters (ADC) - flash



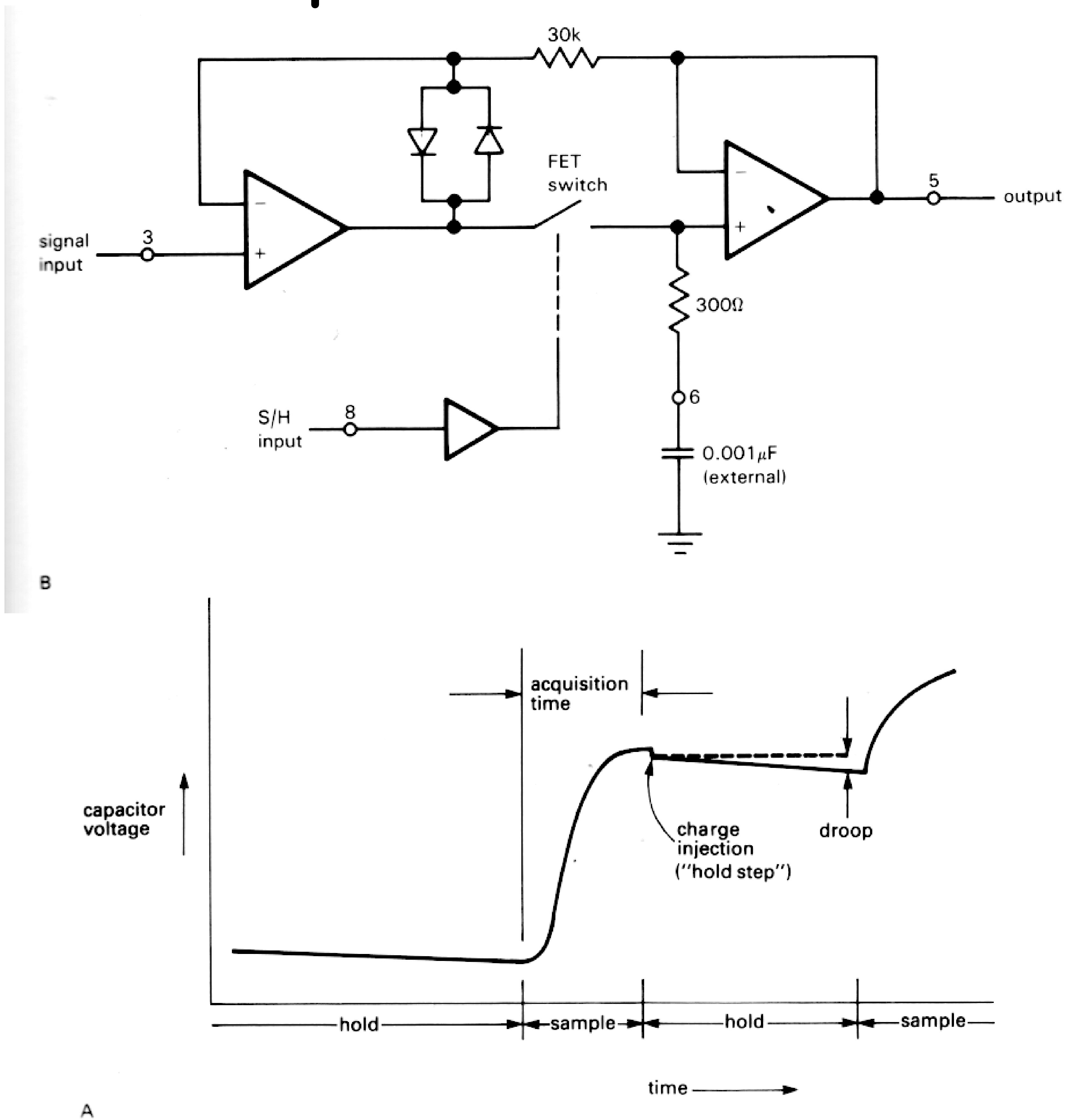
Analog to digital converters (ADC)
"voltage to time"



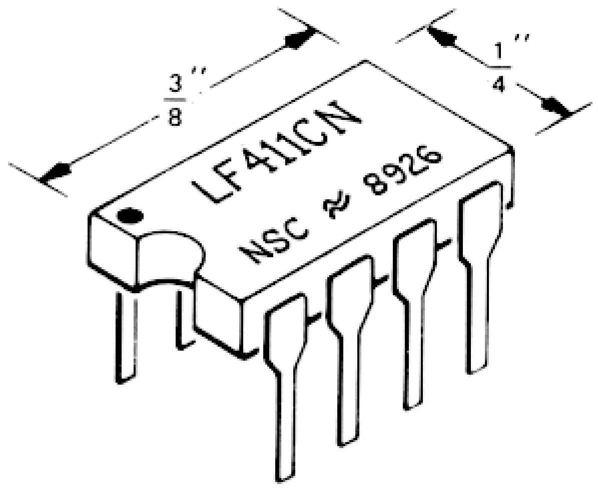
Analog to digital converters (ADC) "successive approximation"

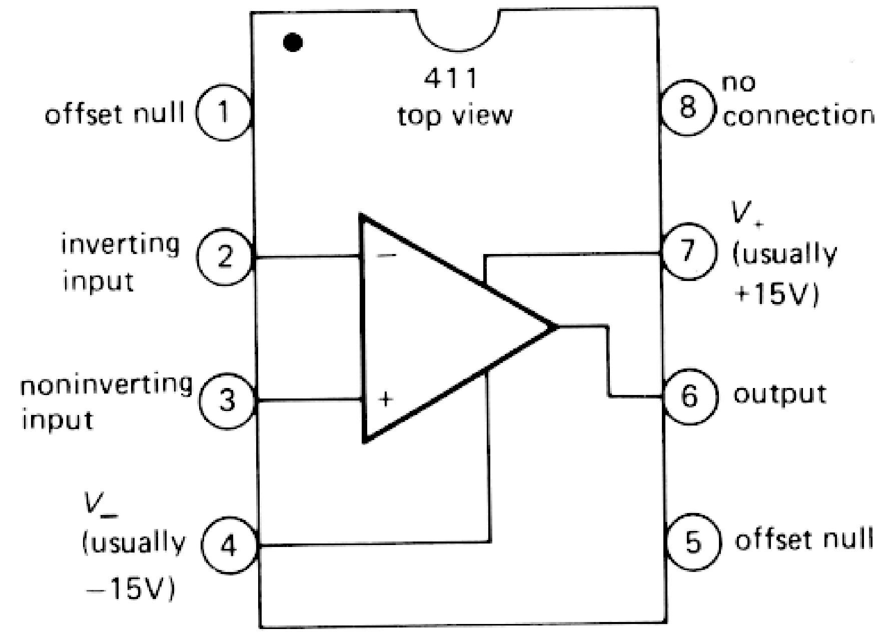


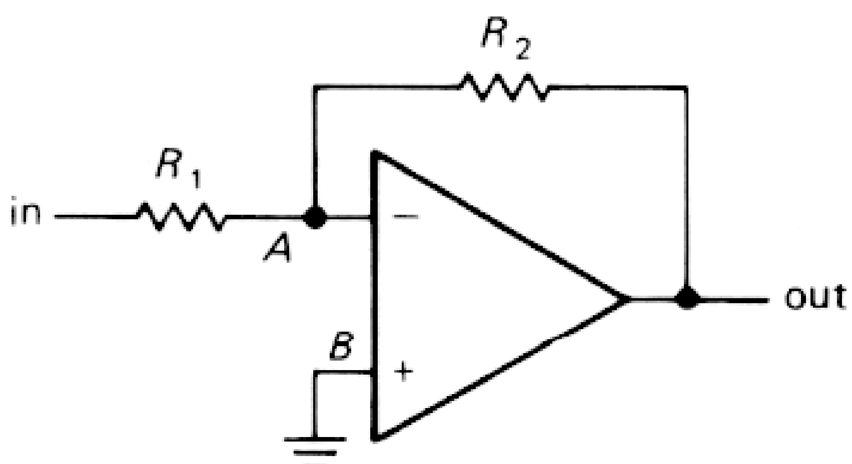
“Sample and hold circuit”



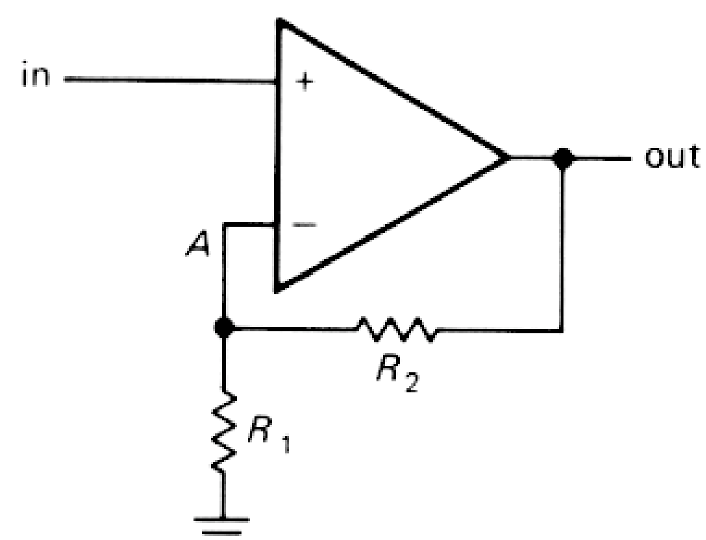
Signal amplification (OpAmps)



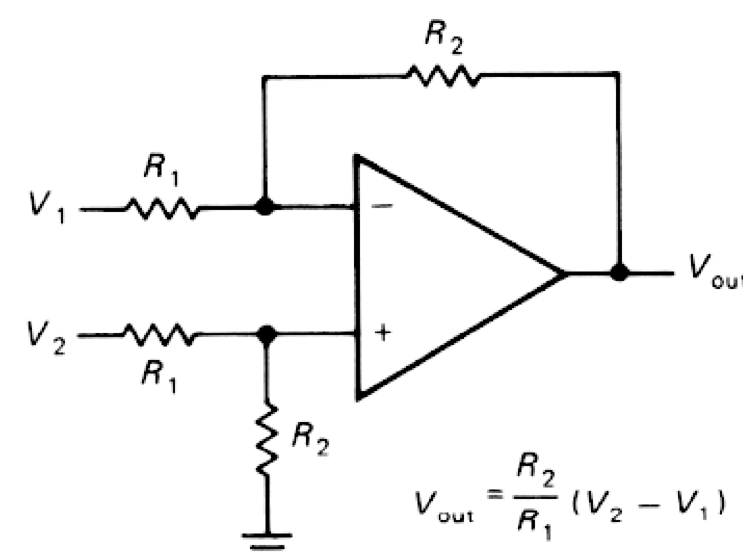




Inverting amplifier



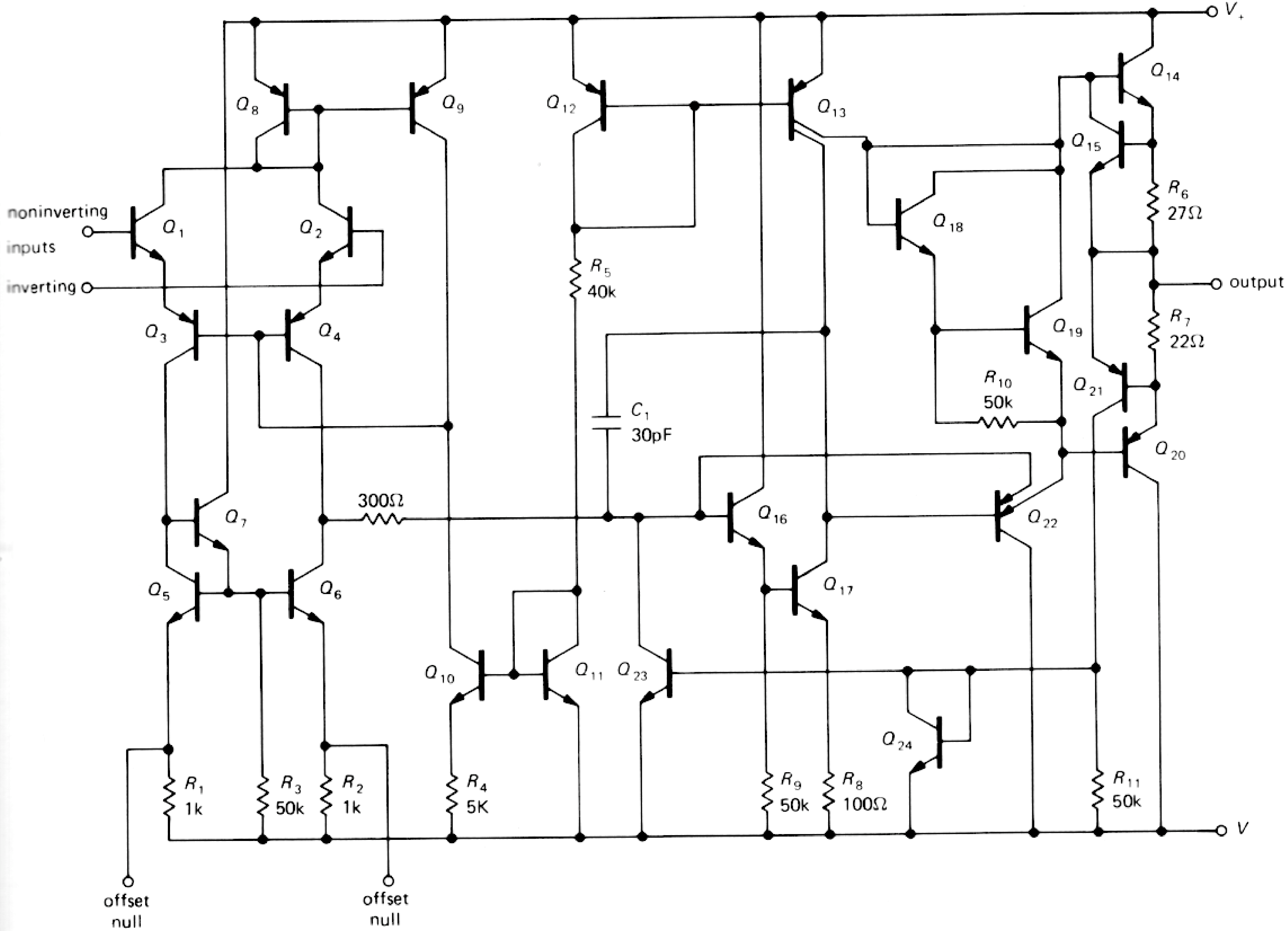
Non-inverting amplifier
- "voltage follower"



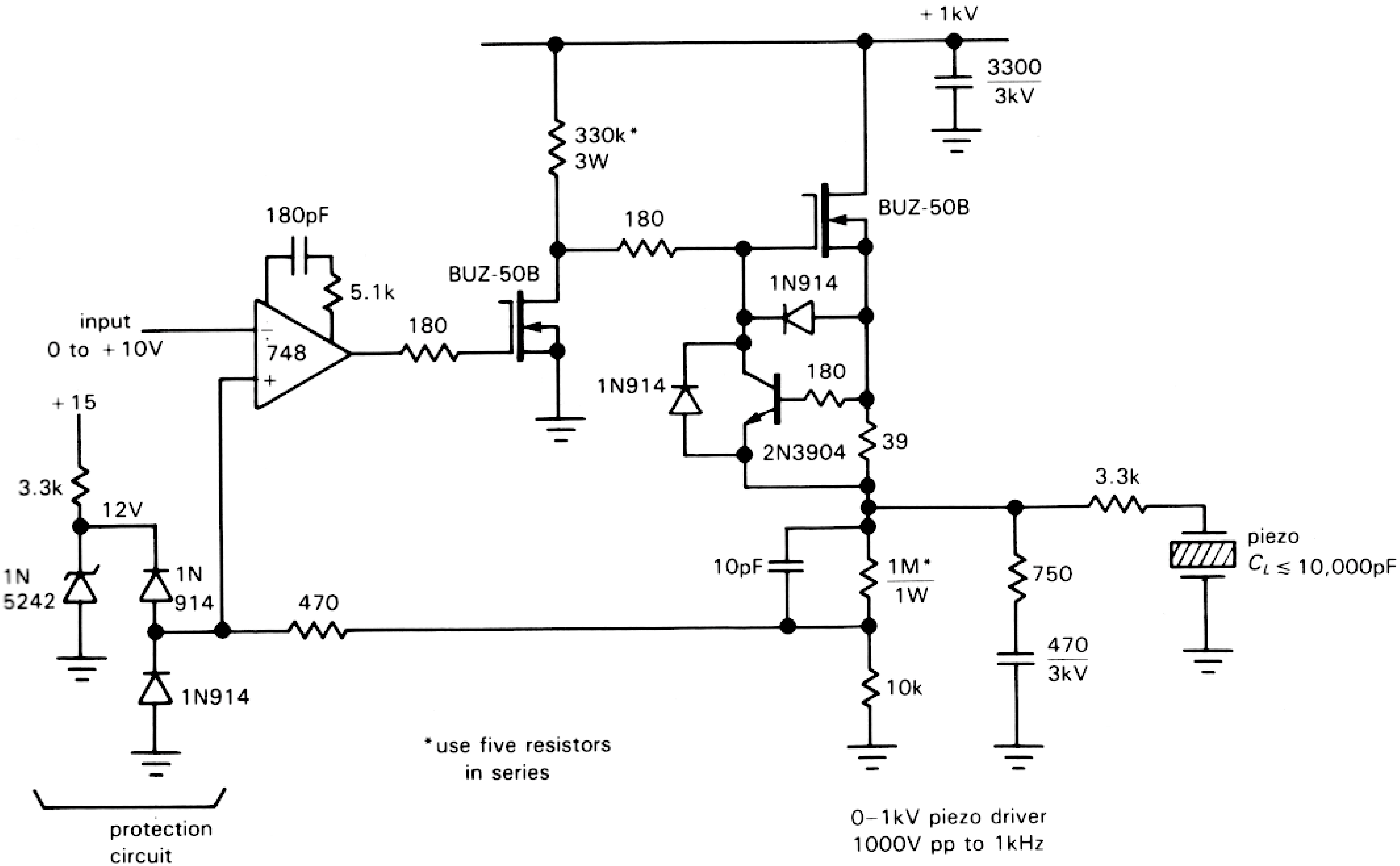
$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

Differential amplifier

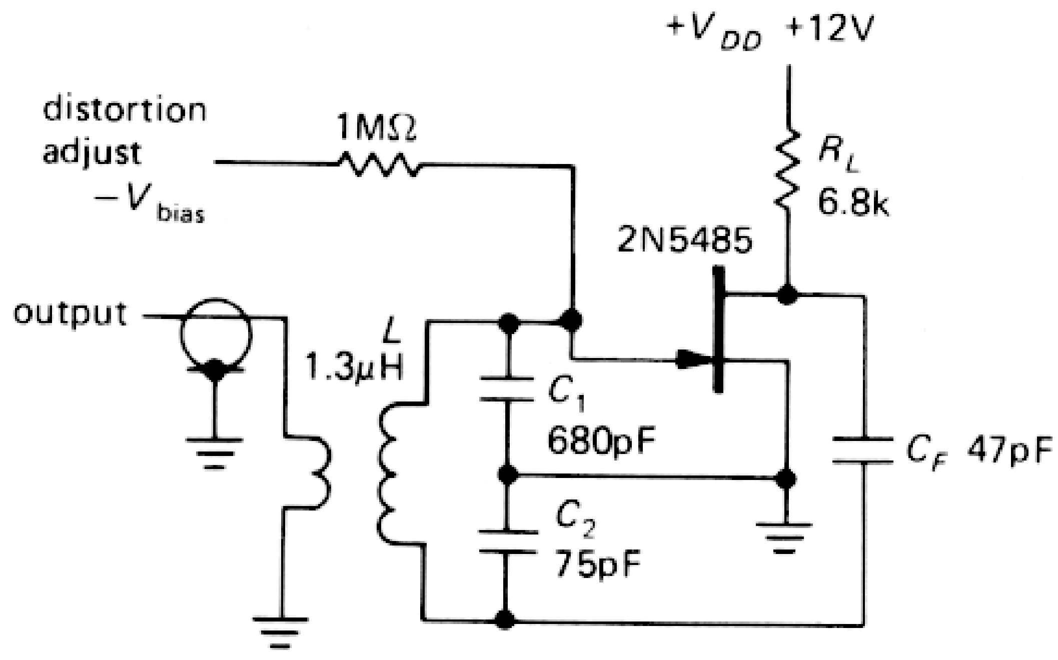
LF411 internal schematics



Example - 1kV piezo driver (2V/μs)

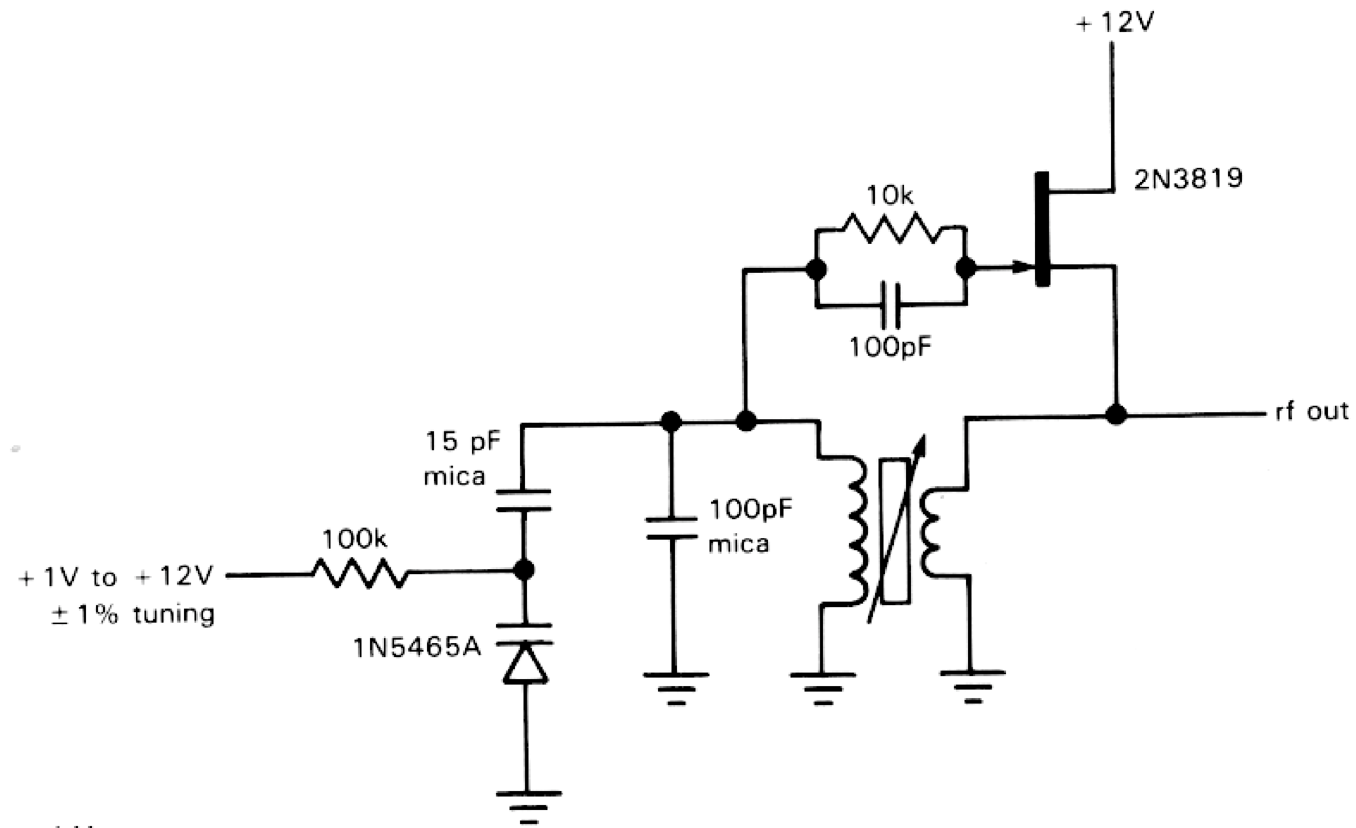


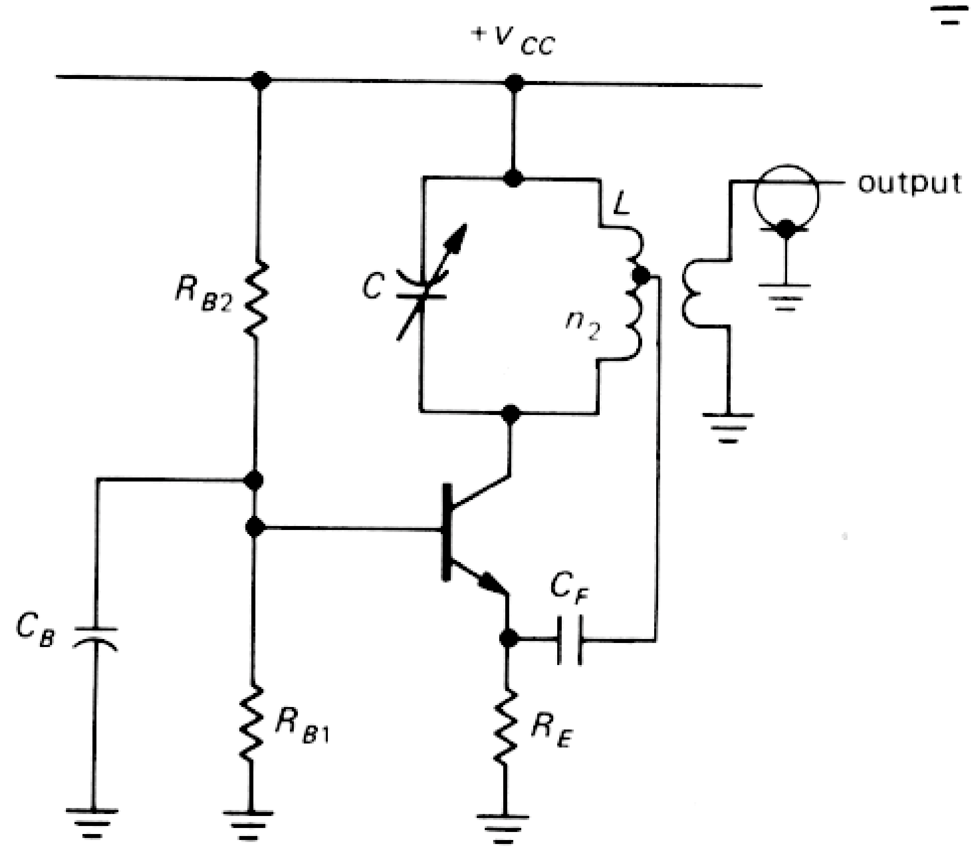
Oscillators



20MHz low-distortion Colpitts oscillator

A

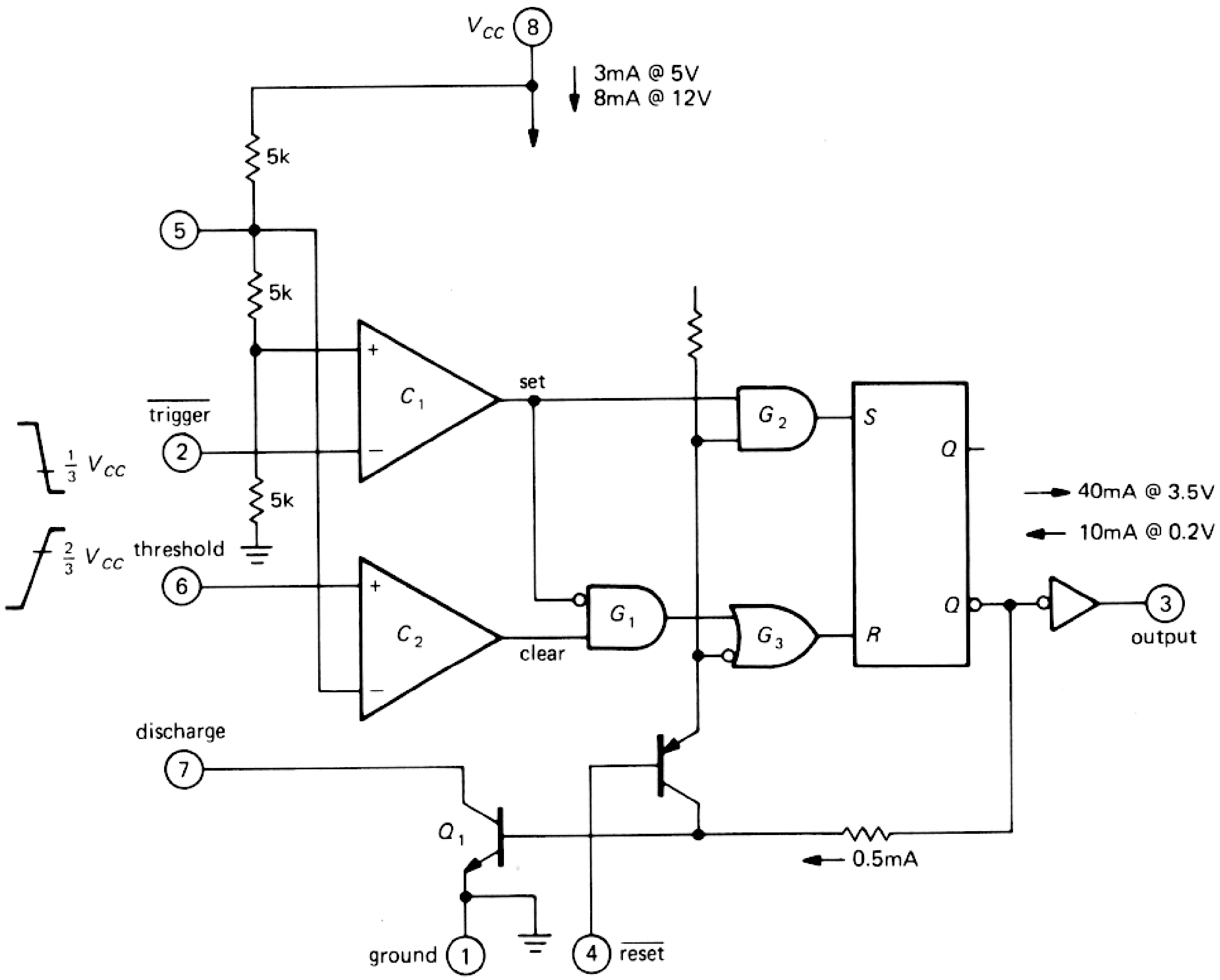


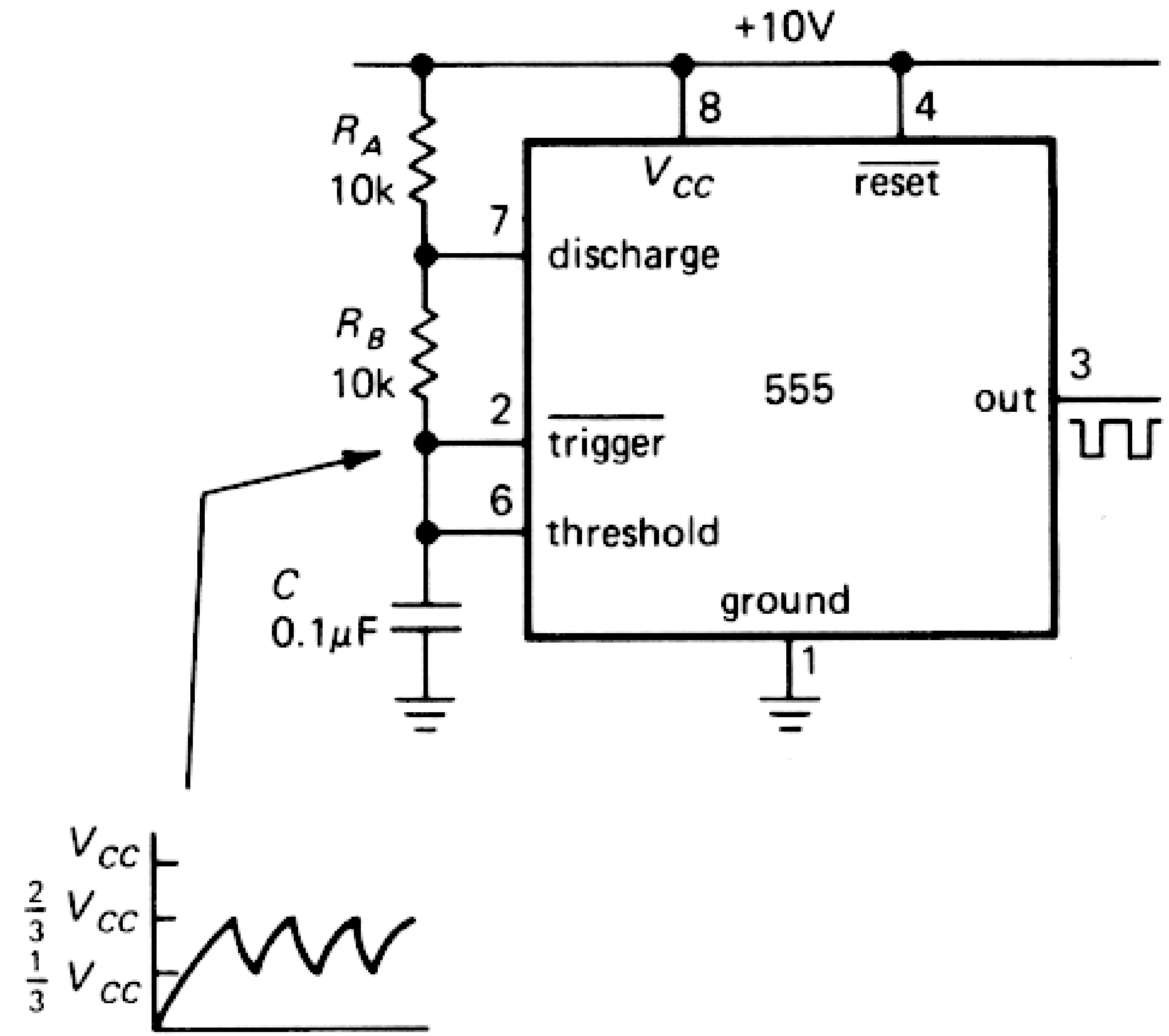


B

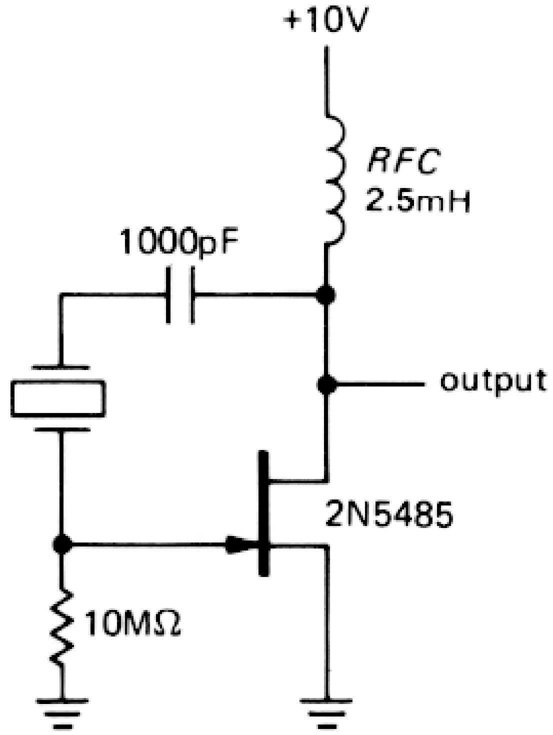
Hartley LC oscillator

Single chip oscillator

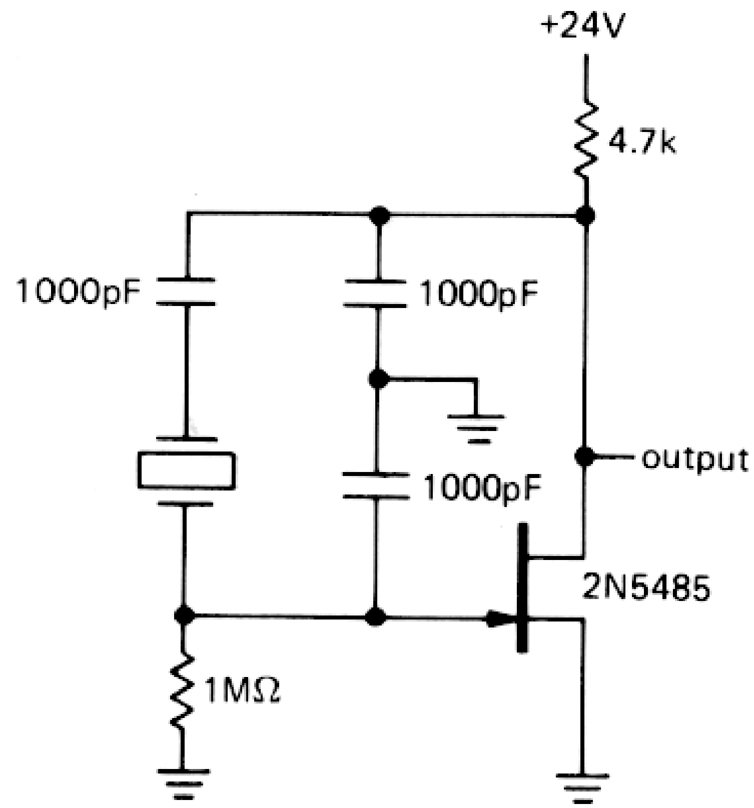




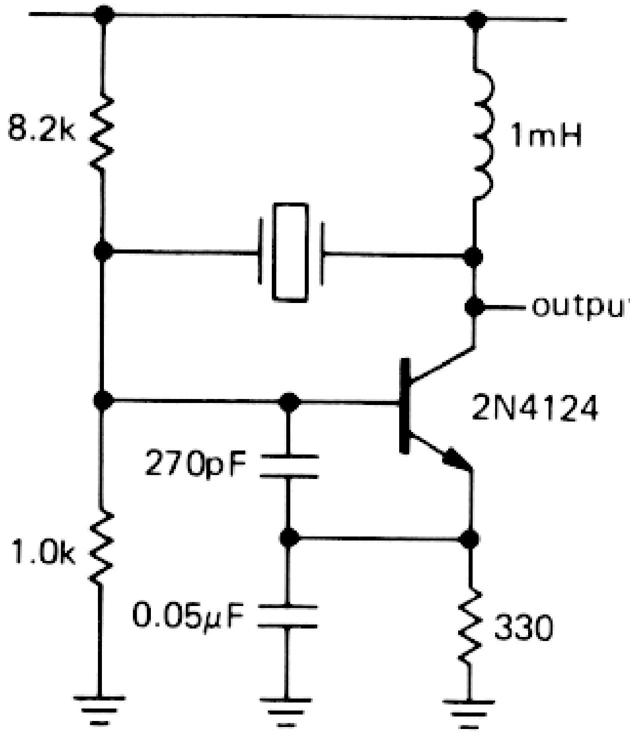
Quartz oscillators



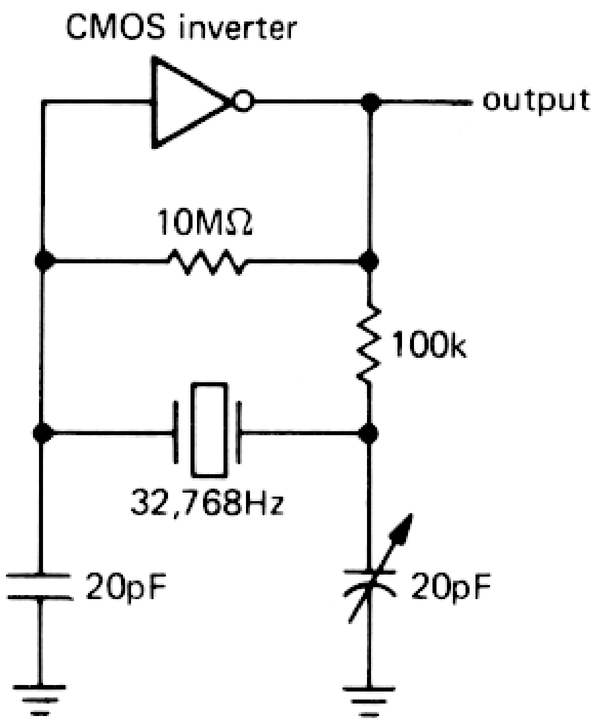
A. Pierce oscillator



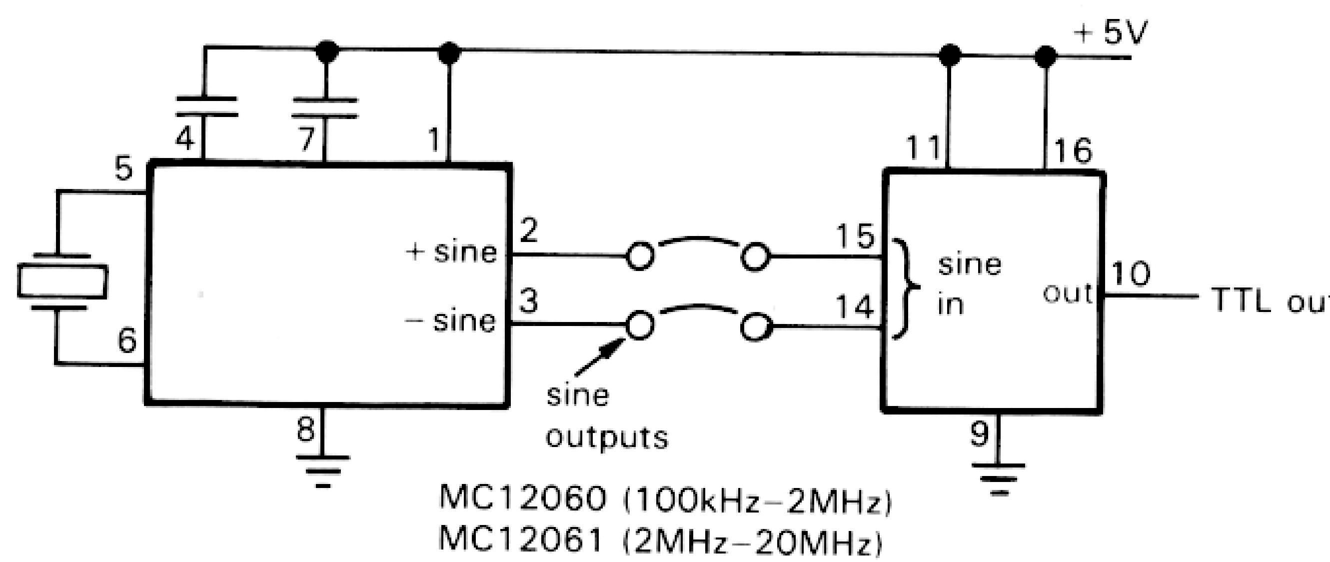
B. Colpitts oscillator



C



D



E

Noise reduction techniques

Main sources of noise:

1) interference excitation of currents in circuit due to EM waves

2) Johnson noise - thermal excitation in resistors:

$$V_J=(4kTRB)^{1/2}$$

e. g. $T=300$, $R=10k\Omega$: $V_J=1.3\ \mu V$

3) shot noise (due to quantization of charge)

$I=(2eI_{dc}B)^{1/2}$

e. g. at 10 kHz bandwidth

1A current has noise of 57 nA (0.000006%)

1μA current has noise of 6 nA (0.006%)

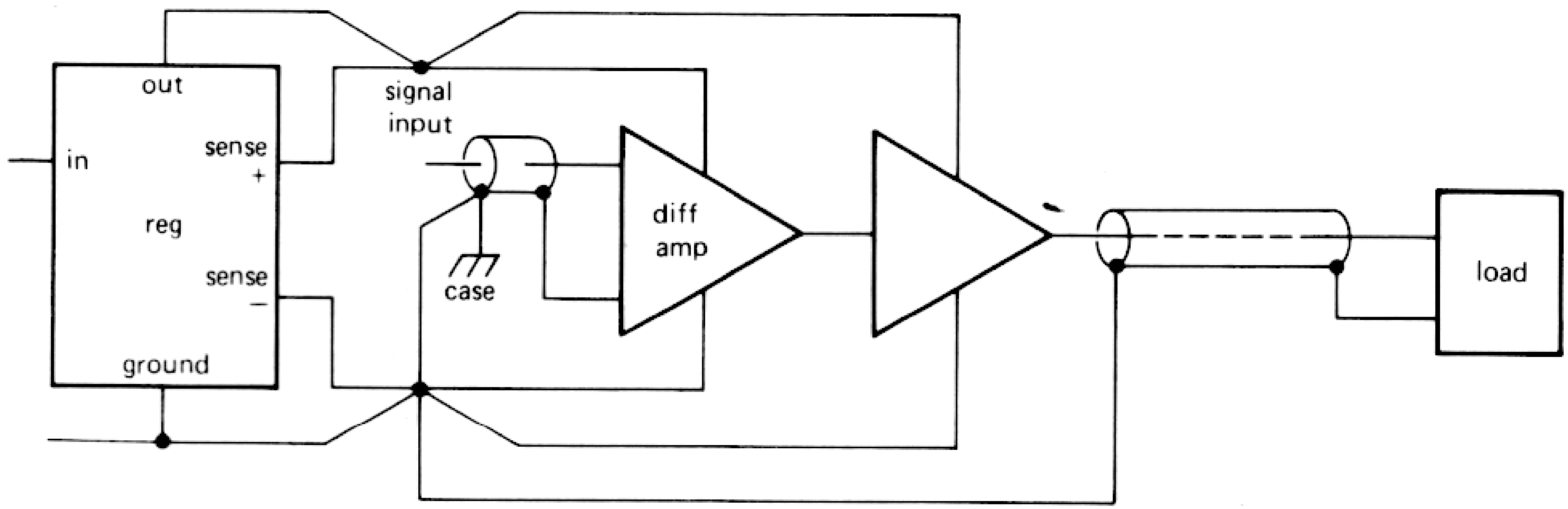
1pA current has noise of 56 fA (5.6%)

4) flicker noise 1/f

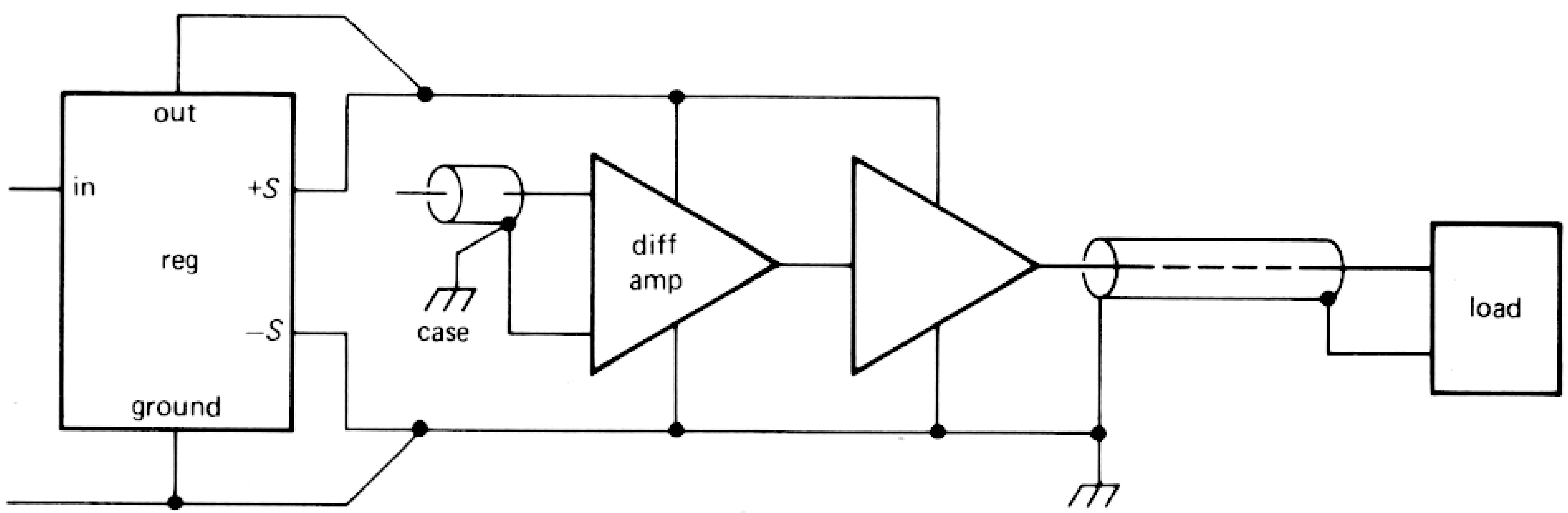
Resistors

Carbon composite	0.1 μV - 3.0 μV
Carbon film	0.05 μV - 0.3 μV
Metal film	0.02 μV - 0.2 μV
Wire wound	0.01 μV - 0.2 μV

Grounding

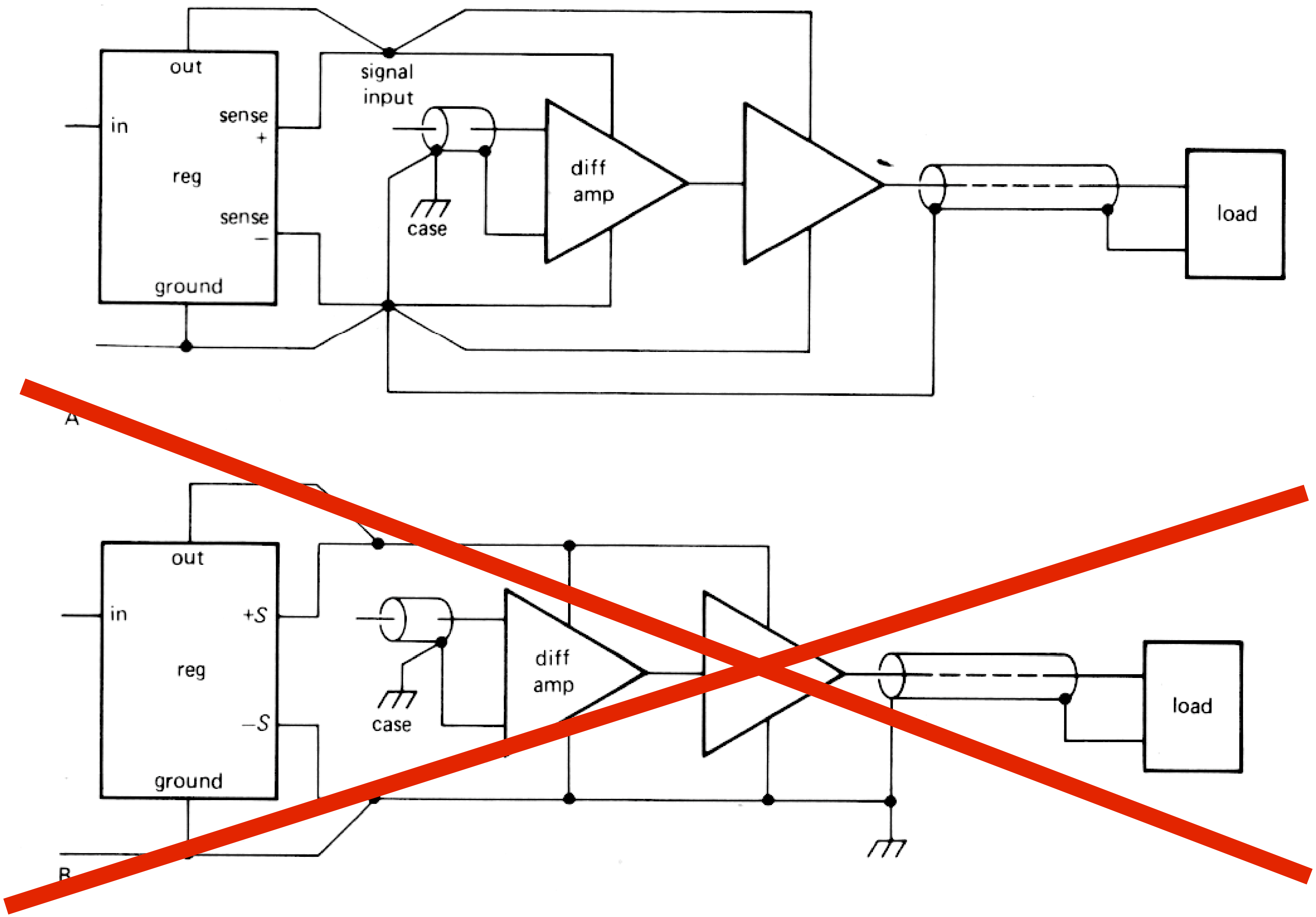


A



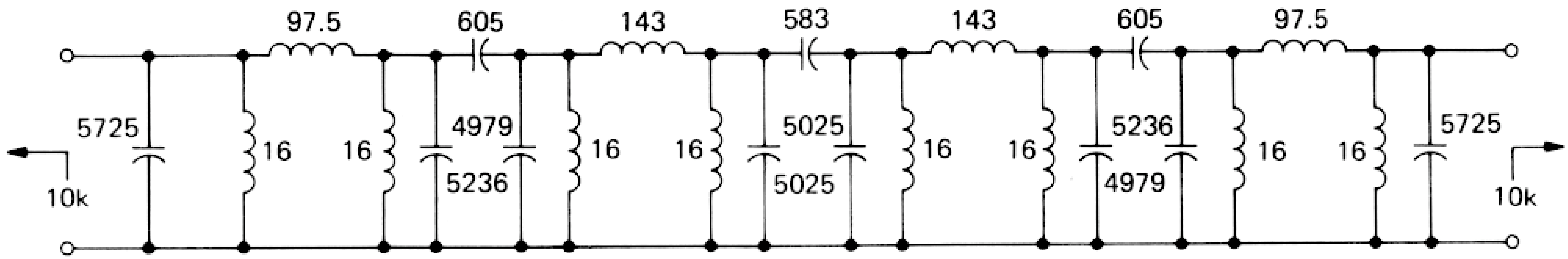
B

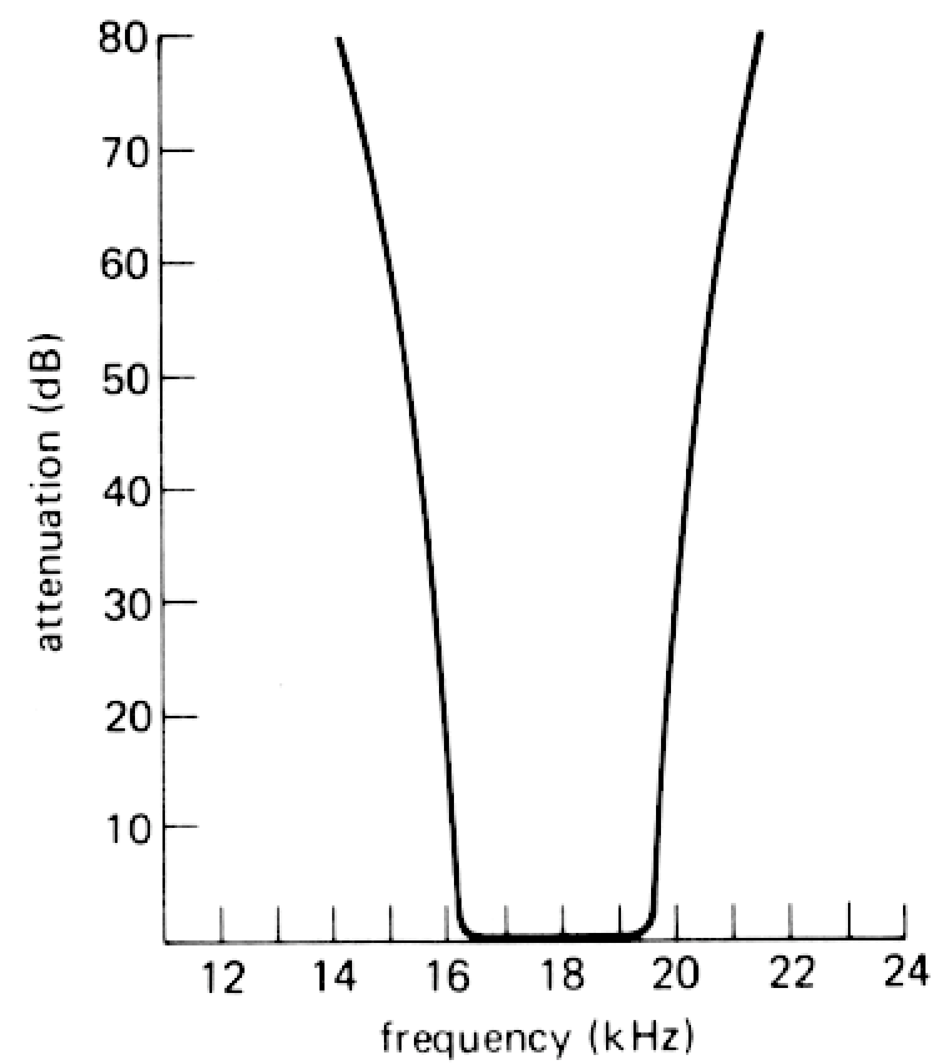
Grounding



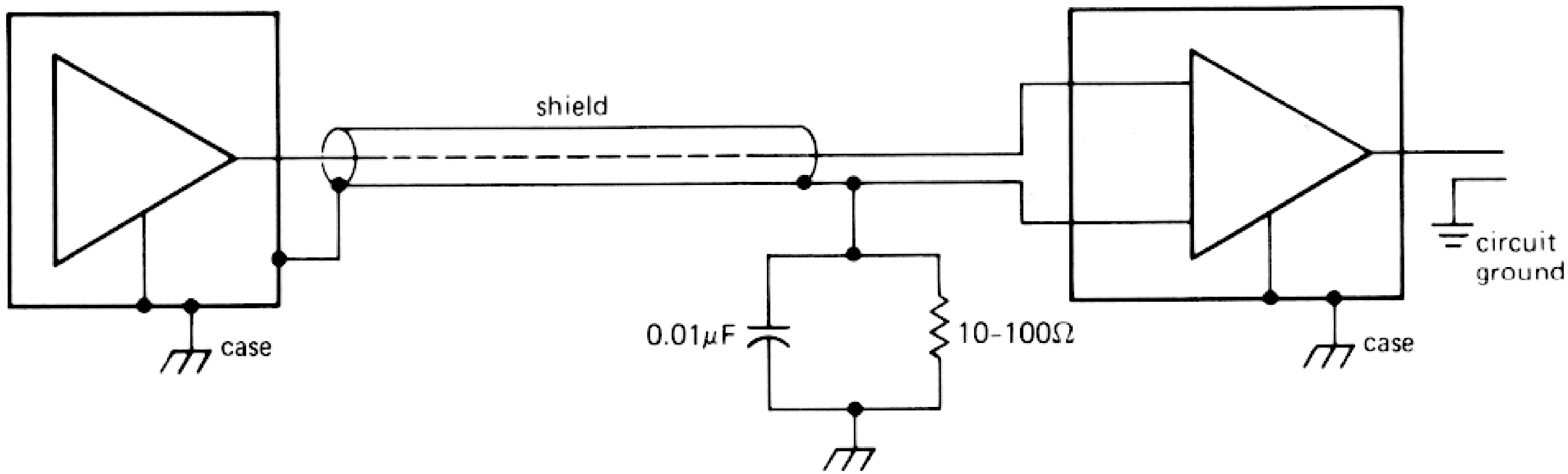
out
in
sense
+
reg
sense
−
ground
signal
input
case
diff
amp
load
A
out
in
+S
reg
−S
ground
case
diff
amp
load
B

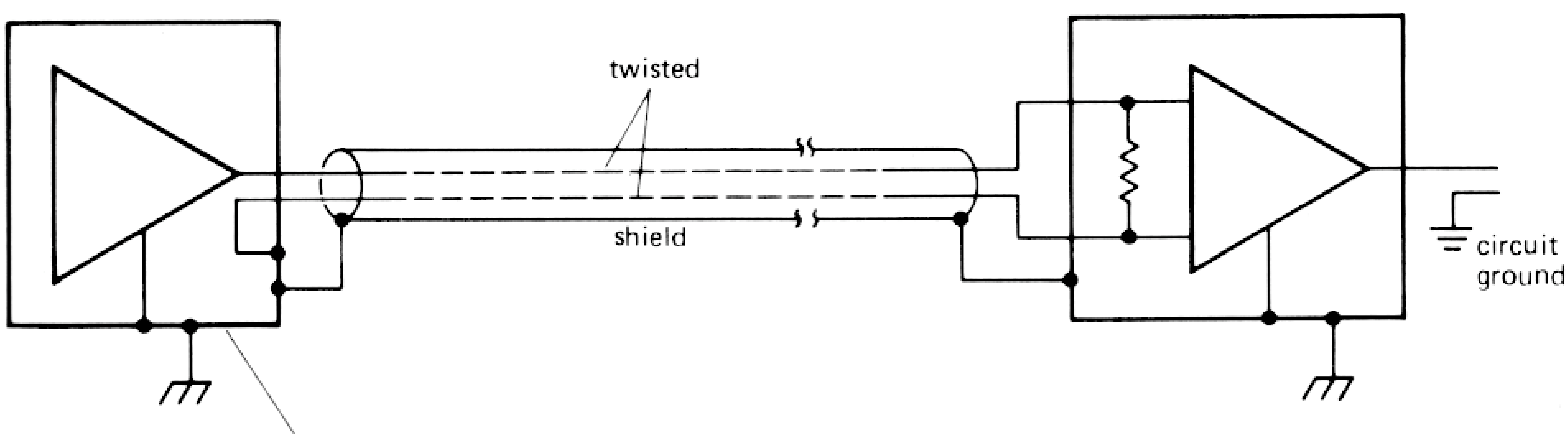
Filters


97.5
605
143
583
143
605
97.5
5725
16
16
4979
5236
16
16
5025
5025
16
16
5236
4979
16
16
5725
10k
10k

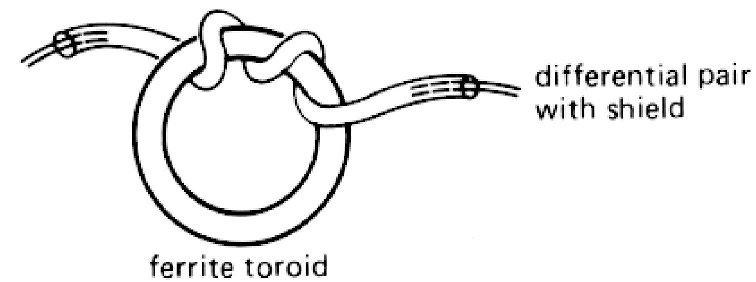

80
70
60
50
40
30
20
10
attenuation (dB)
12
14
16
18
20
22
24
frequency (kHz)

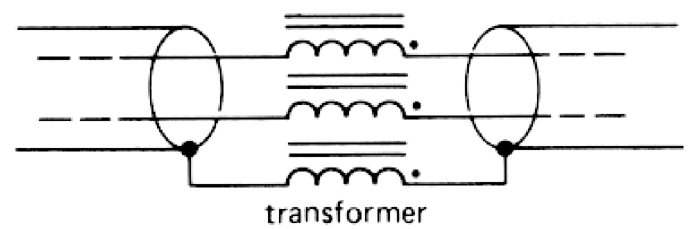
Shielding

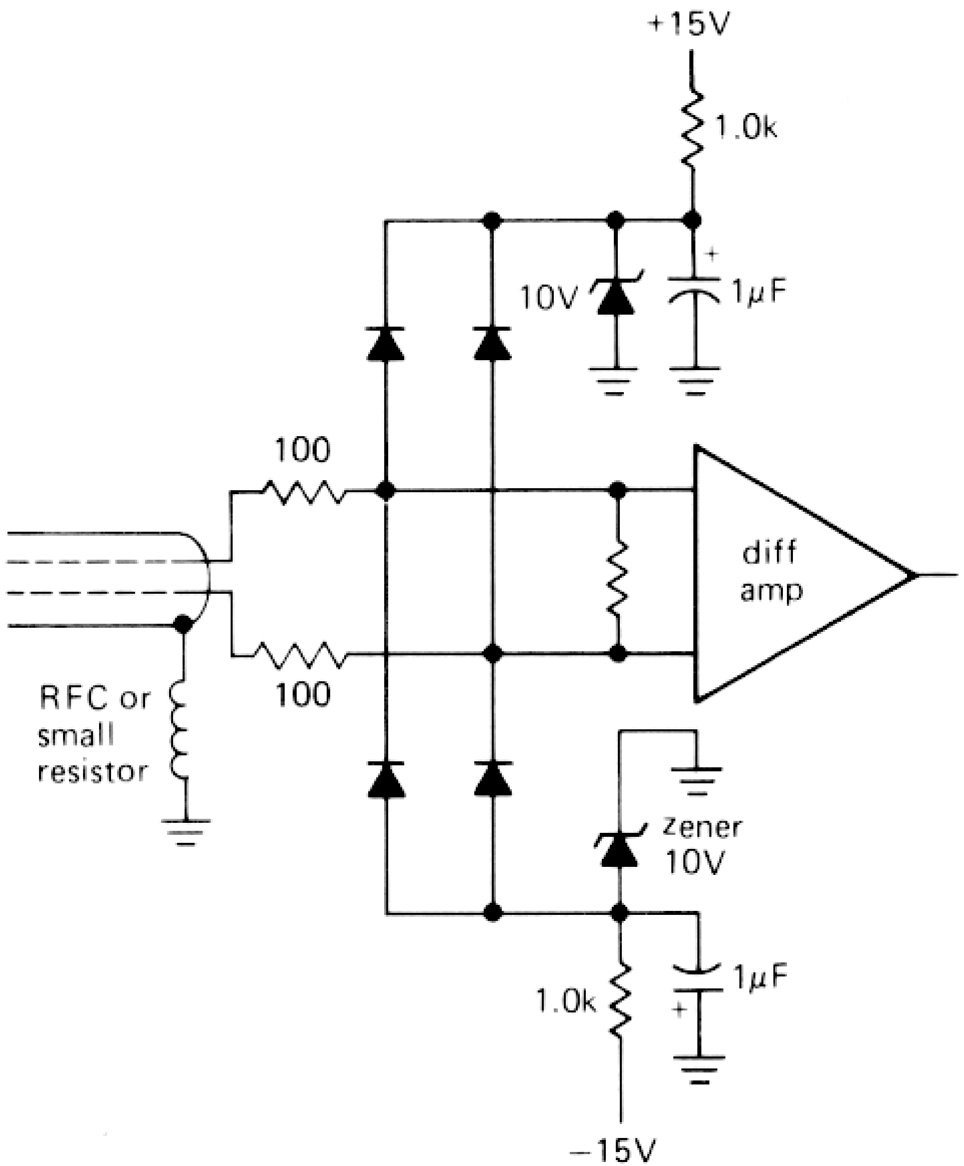

shield
0.01μF
10-100Ω
case
case
circuit ground

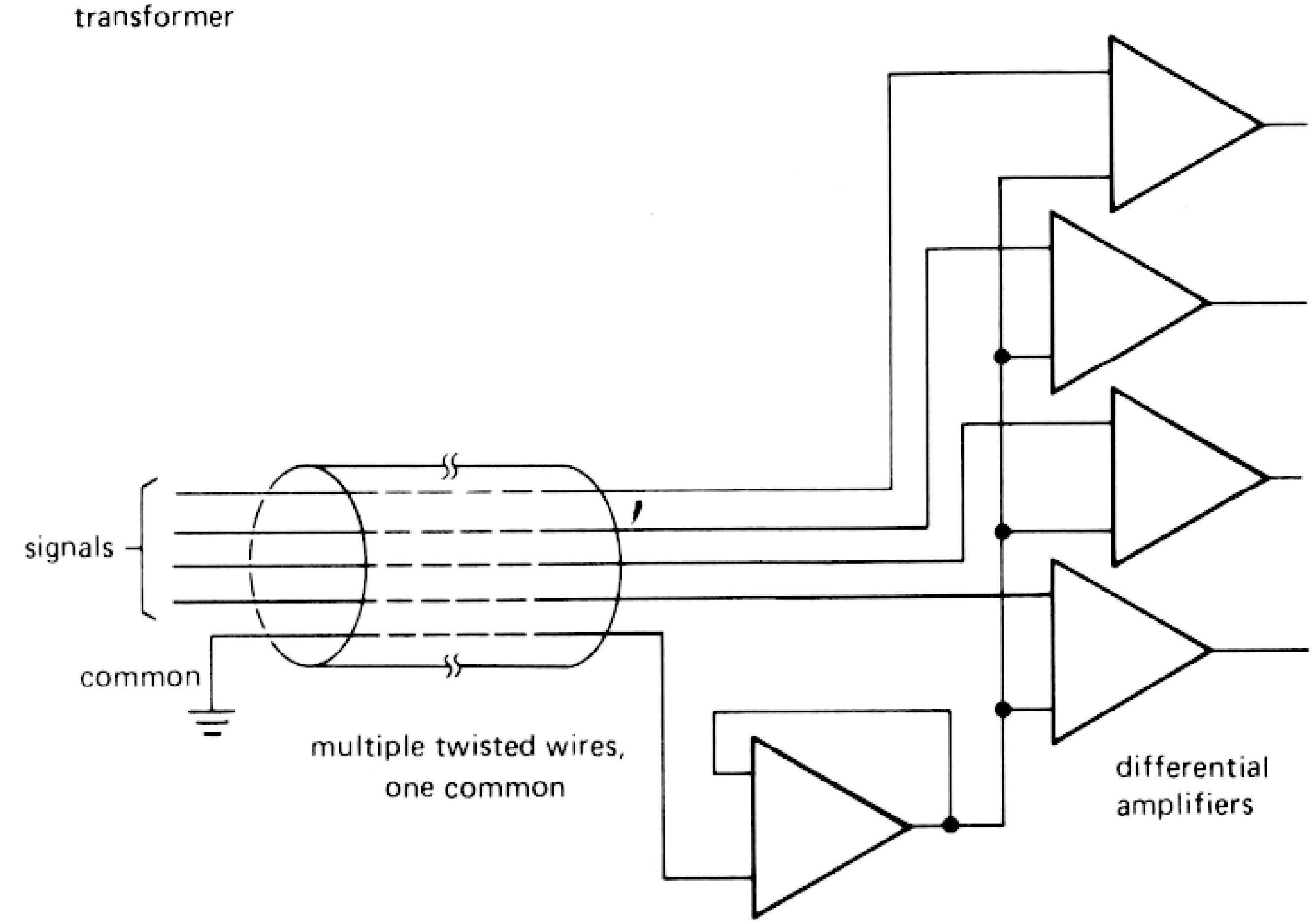

twisted
shield
circuit ground

Noise cancellation

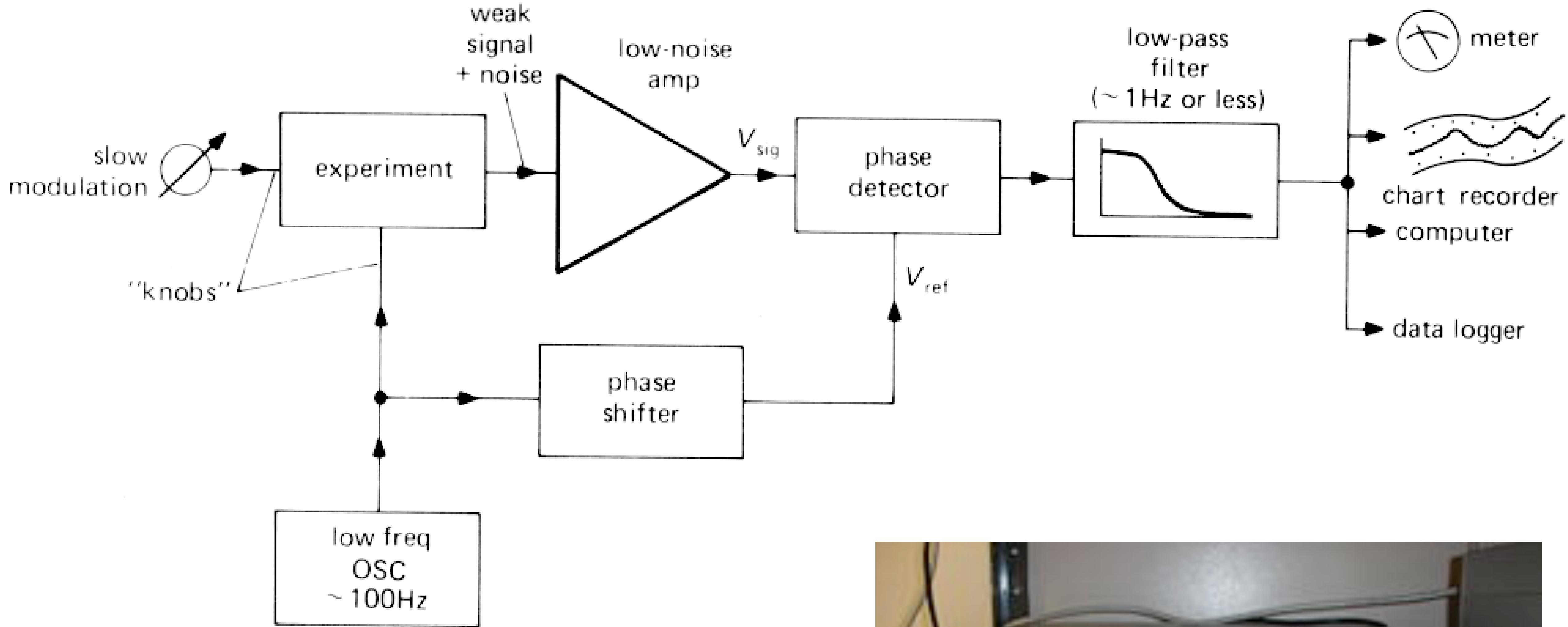








Lock-in measurements



Signal Recovery

Stanford Research Systems